



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

Tipo Doc.: Doc. Type:	TECHNICAL NOTE		Nº DRD: DRD N°:	DEL 069	
Nº Doc.: Doc. N°:	AMSTCS-TN-CGS-008	Ediz.: Issue:	1	Data: Date:	27/03/08
Titolo : CAB TCS STRUCTURAL ANALYSIS REPORT Title :					

	Nome & Funzione Name & Function	Firma Signature	Data Date	LISTA DI DISTRIBUZIONE DISTRIBUTION LIST		
				N	A	I
Preparato da: Prepared by:	Bursi A. (DT/MT)		27-03-08	Interna / Internal		
Approvato da: Approved by:	Duò F. (DT/MT) Vettore C. (SYS) Cremonesi L. (PA/QA) Cinquepalmi C. (PA/CC)	   	27-03-08 27-03-08 27-03-08 27-03-08			
Applicazione autorizzata da: Application authorized by:	Olivier M. (PM)		27-03-08	Esterna / External E. Russo (ASI)		
Customer / Higher Level Contractor						
Accettato da: Accepted by:						
Approvato da: Approved by:						

N=Numero di copie A=Applicazione I=Informazione  
 N=Number of copy A=Application I=Information

Gestione documenti: Data Management:		24/03/08	File: AMSTCS-TN-CGS_008_ls1.doc
-----------------------------------------	--	----------	---------------------------------

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.  
 All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

 <b>CARLO GAVAZZI SPACE SpA</b>	<h1><b>AMS02 - TCS</b></h1> <p>CAB TCS STRUCTURAL ANALYSIS REPORT</p>	N° Doc: Doc N°: <b>AMSTCS-TN-CGS-008</b>  Ediz.: <b>1</b> Data: <b>27/03/08</b> Issue:  Pagina Page <b>2</b> di <b>41</b>
---------------------------------------------------------------------------------------------------------------------	-----------------------------------------------------------------------	------------------------------------------------------------------------------------------------------------------------------------------------

<b>REGISTRAZIONE DELLE MODIFICHE / CHANGE RECORD</b>			
<b>EDIZIONE / ISSUE</b>	<b>DATA / DATE</b>	<b>AUTORIZZAZIONE / CHANGE AUTHORITY</b>	<b>OGGETTO DELLA MODIFICA E SEZIONI AFFETTE / REASON FOR CHANGE AND AFFECTED SECTIONS</b>
1	27/03/08		First Issue

 <b>CARLO GAVAZZI SPACE SpA</b>	<h1 style="text-align: center;">AMS02 - TCS</h1>	N° Doc: Doc N°:		<b>AMSTCS-TN-CGS-008</b>		
		Ediz.:	1	Data:	27/03/08	
CAB TCS STRUCTURAL ANALYSIS REPORT			Pagina Page	3	di of	41

<b>LISTA DELLE PAGINE VALIDE / LIST OF VALID PAGES</b>									
PAGINA PAGE	EDIZIONE ISSUE	PAGINA PAGE	EDIZIONE ISSUE	PAGINA PAGE	EDIZIONE ISSUE	PAGINA PAGE	EDIZIONE ISSUE	PAGINA PAGE	EDIZIONE ISSUE
1 - 41	1								

 <b>CARLO GAVAZZI SPACE SpA</b>	<h1>AMS02 - TCS</h1> <p>CAB TCS STRUCTURAL ANALYSIS REPORT</p>	N° Doc: Doc N°: <b>AMSTCS-TN-CGS-008</b>  Ediz.: <b>1</b> Data: <b>27/03/08</b> Issue:  Pagina Page <b>4</b> di of <b>41</b>
---------------------------------------------------------------------------------------------------------------------	----------------------------------------------------------------	------------------------------------------------------------------------------------------------------------------------------------------------------

## TABLE OF CONTENT

<b>1. SCOPE.....</b>	<b>6</b>
<b>2. RELEVANT DOCUMENTS.....</b>	<b>7</b>
2.1 APPLICABLE DOCUMENTS.....	7
2.2 REFERENCE DOCUMENTS .....	7
<b>3. ACRONYMS AND ABBREVIATIONS .....</b>	<b>7</b>
<b>4. CAB LOOP HEAT PIPES FLIGHT HARDWARE DESCRIPTION .....</b>	<b>8</b>
<b>5. CAB LOOP HEAT PIPES FEM DESCRIPTION.....</b>	<b>11</b>
5.1 USED SOFTWARE .....	15
5.2 MODEL UNITS .....	15
5.3 MODEL COORDINATE SYSTEM .....	16
5.4 MODEL MATERIALS.....	18
5.4.1 STAINLESS STEEL AISI 316L .....	18
5.5 MODEL BOUNDARY CONDITIONS.....	19
5.6 MODEL MASS BUDGET.....	20
<b>6. DIMENSIONING LOADS .....</b>	<b>25</b>
<b>7. DIMENSIONING RULES .....</b>	<b>26</b>
7.1 SAFETY FACTORS.....	26
7.2 TEMPERATURE DERATING FACTOR.....	26
7.3 MARGINS OF SAFETY FOR STRUCTURE.....	26
<b>8. DYNAMIC ANALYSIS.....</b>	<b>27</b>
8.1 DYNAMIC ANALYSIS FOR CAB TCS .....	27
8.1.1 EIGENFREQUENCIES AND MODE SHAPES FOR CAB TCS .....	27
<b>9. STATIC ANALYSIS .....</b>	<b>33</b>
9.1 DISPLACEMENT ANALYSIS .....	33
9.2 STRESS ANALYSIS.....	35
9.2.1 LOOP HEAT PIPES TRANSPORT LINES .....	36
9.2.2 MARGINS OF SAFETY .....	39
<b>10. CONCLUSIONS AND COMMENTS.....</b>	<b>40</b>
<b>ANNEX 1.....</b>	<b>41</b>

## LIST OF TABLES

Table 5-1: Model summary .....	15
Table 5-2: AISI 316L properties .....	18
Table 5-3: AISI 316L in FE model .....	18
Table 5-4: WAKE Radiator updated mass budget.....	20
Table 5-5: FEM mass properties, free-free modes, hardmounted modes .....	21
Table 5-6: FEM 1g check.....	22
Table 5-7: FEM Strain Energy check .....	24
Table 6-1: Applied set of load cases .....	25
Table 7-1: Safety Factors for structure .....	26
Table 8-1: CAB TCS natural frequencies .....	27
Table 9-1: MoS summary.....	39

 <b>CARLO GAVAZZI</b> <b>CARLO GAVAZZI SPACE SpA</b>	<h1>AMS02 - TCS</h1> <p>CAB TCS STRUCTURAL ANALYSIS REPORT</p>	Nº Doc: Doc N°: <b>AMSTCS-TN-CGS-008</b>  Ediz.: <b>1</b> Data: <b>27/03/08</b> Issue:  Pagina Page <b>5</b> di <b>41</b>
---------------------------------------------------------------------------------------------------------------------------------------------	----------------------------------------------------------------	------------------------------------------------------------------------------------------------------------------------------------------------

## LIST OF FIGURES

Figure 4-1: General view of AMS-02.....	8
Figure 4-2: CAB TCS LHP of AMS-02 WAKE Radiator.....	8
Figure 4-3: LHP liquid and vapour tubes connection points to the evaporators and routing to the WAKE radiator.....	9
Figure 4-5: CAB TCS LHP of AMS-02 WAKE Radiator general view.....	10
Figure 5-1: General view of the WAKE and Tracker Radiators .....	11
Figure 5-2: CAB-Trunnion fixing points. The red circles ihighlight the four bolted junction.....	12
Figure 5-3 LHP (liquid and vapour lines) FEM model. RBE3 elements simulate the rigid connection between CAB and USS-Trunnion bridge. RBE2 element simulates the rigid connection between each LHP transport line. Finally the LHP connection point scheme is shown.....	13
Figure 5-4: Loop Heat Pipes liquid tubes .....	14
Figure 5-5: Loop Heat Pipes vapor tubes .....	14
Figure 5-6: <i>LHP transport lines-WAKE radiator fixing points. The red square highlights the node coincidence zone .....</i>	15
Figure 5-7: AMS-02 coordinate system.....	16
Figure 5-8: Main Radiators dimensions .....	17
Figure 5-9: Model boundary conditions for WAKE Radiator .....	19
Figure 5-64: 1G check analysis run results for CAB TCS side .....	23
Figure 8-1: CAB TCS system mode 1at 21.33 Hz .....	28
Figure 8-2: Loop Heat Pipes transport lines mode 2 at 26.28 Hz .....	28
Figure 8-3: CAB TCS system mode 3 at 29.84 Hz .....	29
Figure 8-4: CAB TCS system mode 4 at 31.99 Hz .....	29
Figure 8-5: CAB TCS system mode 5 at 33.67 Hz .....	30
Figure 8-6: CAB TCS system mode 6 at 34.09 Hz .....	30
Figure 8-7: CAB TCS system mode 7 at 38.30 Hz .....	31
Figure 8-8: CAB TCS system mode 8 at 53.33 Hz .....	31
Figure 8-9: CAB TCS system mode 9 at 58.29 Hz .....	32
Figure 8-10: CAB TCS system mode 15 at 70.72 Hz .....	32
Figure 9-1: Deformation – Load case 1032 .....	33
Figure 9-2: Relative displacement LHP transport lines – USS trunnion bridge – Load case 1017 .....	34
Figure 9-3: LHP bar, Load Case 1017 .....	36
Figure 9-4: Pressure induced stresses 1 .....	37
Figure 9-5: Pressure induced stresses 2 .....	37

 <b>CARLO GAVAZZI</b> <b>CARLO GAVAZZI SPACE SpA</b>	<h1>AMS02 - TCS</h1> <p>CAB TCS STRUCTURAL ANALYSIS REPORT</p>	N° Doc: Doc N°: <b>AMSTCS-TN-CGS-008</b>  Ediz.: Issue: <b>1</b> Data: Date: <b>27/03/08</b>  Pagina Page <b>6</b> di of <b>41</b>
---------------------------------------------------------------------------------------------------------------------------------------------	----------------------------------------------------------------	---------------------------------------------------------------------------------------------------------------------------------------------------------------

## 1. SCOPE

This document corresponds to contract deliverable DEL 069.

The verification by analysis of the structural requirements of CAB TCS Loop Heat Pipes (on WAKE radiators) is provided.

The model used in this document contains the following items:

- TCS Wake and Tracker Radiators Panel
- TCS Wake and Tracker Radiators Structure
- USS Trunion Bridge
- TCS CAB Loop Heat Pipes transport lines.

The model description of TCS Main Radiator Panels, TCS Main Radiators Structure and USS Trunion Bridge is presented in RD 8.

Results of this document are related only to CAB TCS Loop Heat Pipes transport lines structure while results of TCS Main and Tracker radiators are reported in RD 8.

The result of these analyses demonstrates that the design of the CAB Loop Heat Pipes transport lines is compliant with the structural requirements of AD 1.

A summary of the requirements follow:

- All MoS positive, under applicable design loads (AD 1)

The tables with the input for the safety review are shown in ANNEX 1.

 <b>CARLO GAVAZZI</b> <b>CARLO GAVAZZI SPACE SpA</b>	<h1>AMS02 - TCS</h1>	Nº Doc: Doc N°: <b>AMSTCS-TN-CGS-008</b>
	CAB TCS STRUCTURAL ANALYSIS REPORT	Ediz.: 1 Data: 27/03/08 Issue: Date:

Pagina 7 di 41

## 2. RELEVANT DOCUMENTS

### 2.1 APPLICABLE DOCUMENTS

AD # (ID)	Doc Number	Issue	Date	Rev	Title
AD 1	JSC-28792		August, 2003	C	AMS-02 STRUCTURAL VERIFICATION PLAN

### 2.2 REFERENCE DOCUMENTS

RD # (ID)	Doc Number	Issue	Date	Rev	Title
RD. 1	MIL-HDBK-5	H	Dec, 1998		Metallic Materials and Elements for Aerospace Vehicle Structures
RD. 2	File MathCad				LMSO bolt verification guidelines
RD 3	SSP-57003		05/08/02	A	Attached Payload Interface Requirements Document
RD 4			Jun, 1973		Bruhn - Analysis and Design of Flight Vehicle Structures
RD 5	NSTS 1700.7B		13/01/89		Safety policy and requirements for payloads using the space transportation system
RD 6	NSTS 1700.7B ISS ADD				Safety Policy and Requirements
RD 7	SSP 52000-IDD-EPP	Draft 5	10-Oct-01		Express Pallet Payloads Interface Definition Document
RD 8	AMSTCS-TN-CGS-007	1	25/03/08		Main and Tracker Radiators Structural Analysis Report
RD 9	B-TR60-0368	1	23/08/2007	0	AMS-02 Static and Dynamic Tests Modal Test Report

## 3. ACRONYMS AND ABBREVIATIONS

AMS	Alpha Magnetic Spectrometer
CAB	Cryomagnet Avionics Box
EID	Element Identification
EVA	Extra Vehicular Activity
FEM	Finite Element Model
LC	Load Case
LHP	Loop Heat Pipes
MoS	Margin Of Safety
N/A	Not Available
SAR	Structural Analysis Report
SF	Safety Factor
SPC	Single Point Constrain
TBD	To Be Defined
TCS	Thermal Control System
USS	Unique Support Structure



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc: AMSTCS-TN-CGS-008  
Doc N°:  
Ediz.: 1 Data: 27/03/08  
Issue:  
Pagina 8 di 41  
Page

## 4. CAB LOOP HEAT PIPES FLIGHT HARDWARE DESCRIPTION

Next image shows the TCS Main Radiators position onto AMS-02.

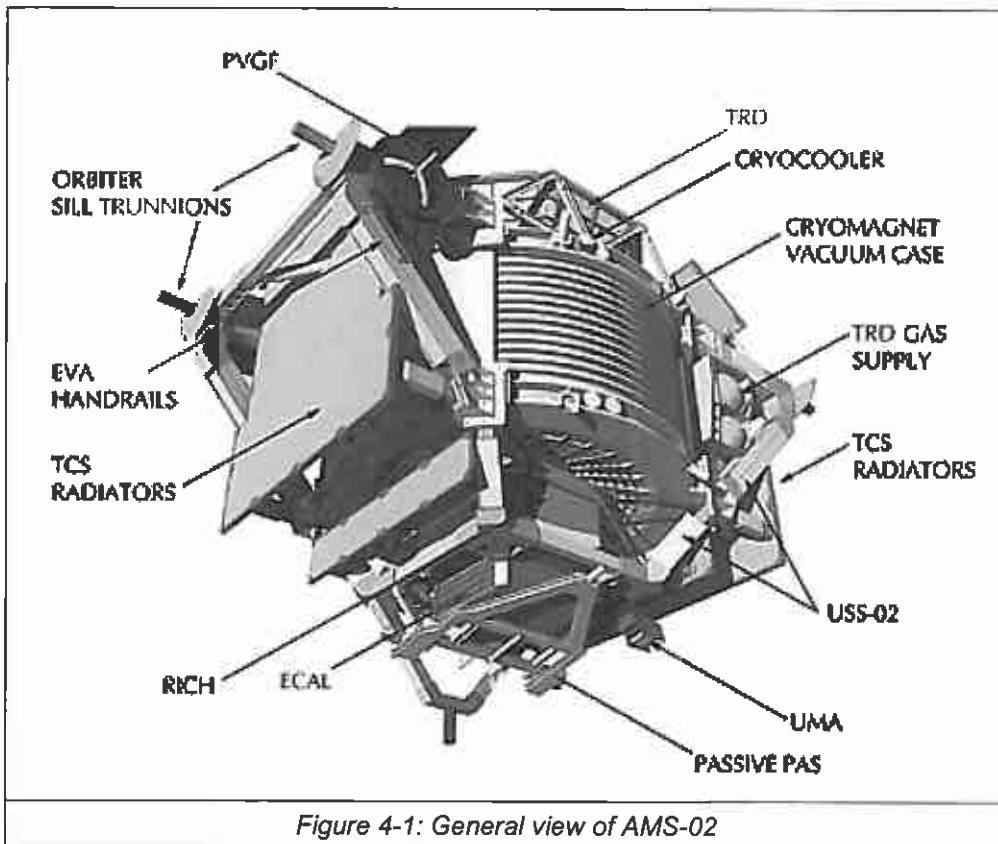


Figure 4-1: General view of AMS-02

The following figure shows the LHP on the WAKE main radiators.

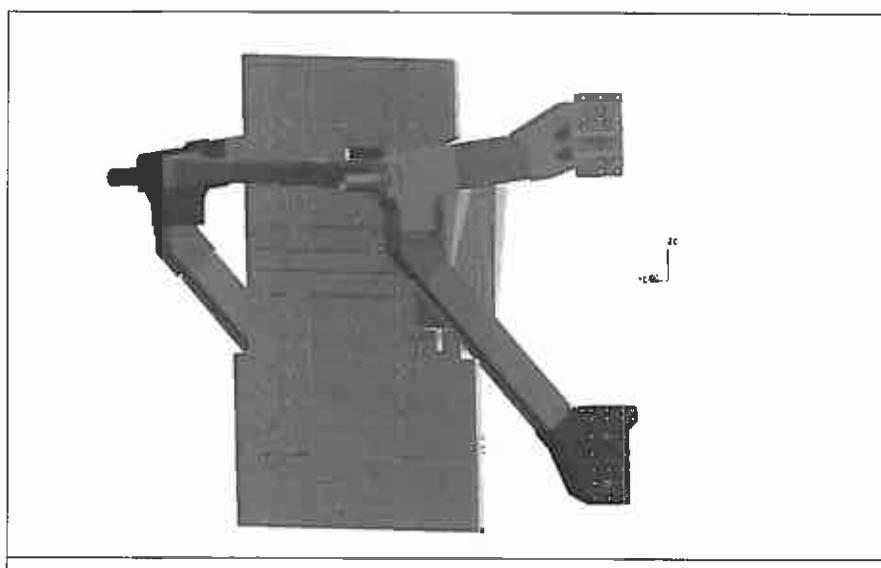


Figure 4-2: CAB TCS LHP of AMS-02 WAKE Radiator

The LHP liquid and vapour tubes design details are shown in the following figures.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.  
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.



CARLO GAVAZZI SPACE SpA

# AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc: AMSTCS-TN-CGS-008  
Doc N°:

Ediz.: 1 Data: 27/03/08  
Issue: Date:

Pagina 9 di 41  
Page

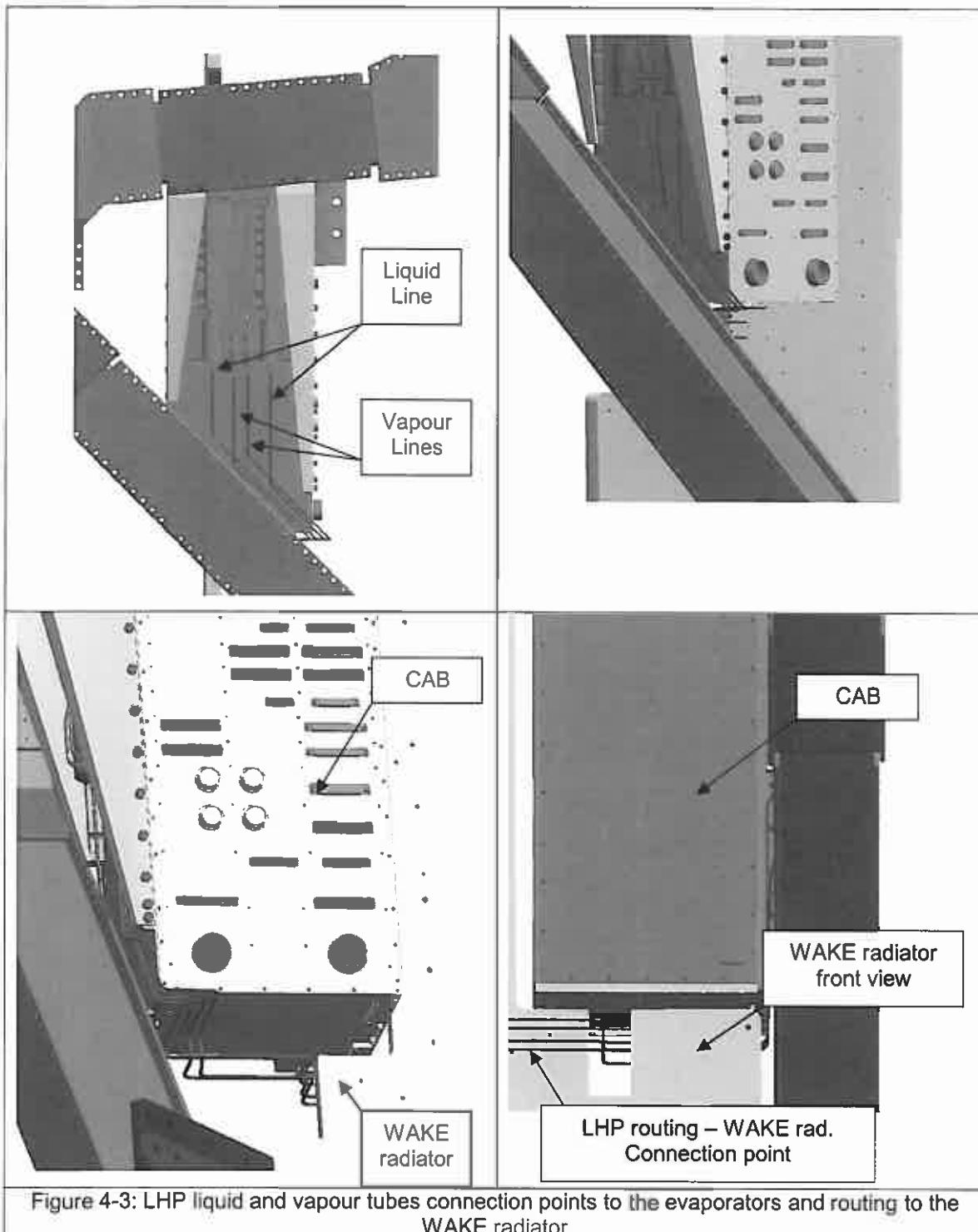


Figure 4-3: LHP liquid and vapour tubes connection points to the evaporators and routing to the WAKE radiator



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°:

AMSTCS-TN-CGS-008

Ediz.:  
Issue:1  
Pagina  
PageData:  
Date:

27/03/08

10

di  
of

41

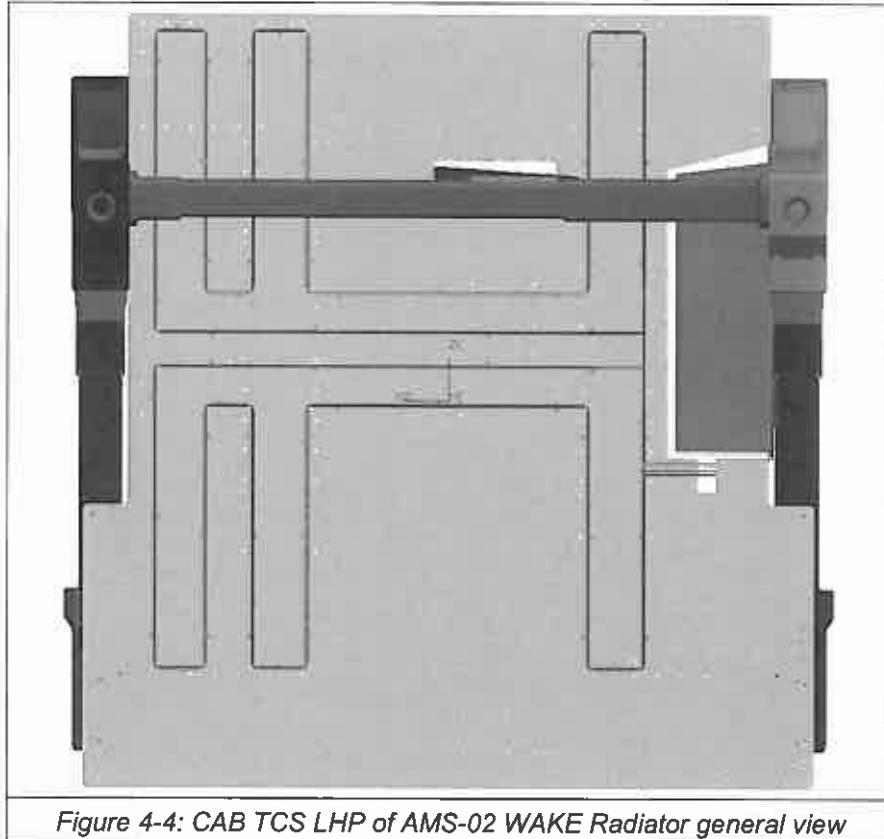


Figure 4-4: CAB TCS LHP of AMS-02 WAKE Radiator general view

The liquid and vapour tubes are flexible lines that have to connect the evaporators installed on the CAB with the LHP condenser line on the WAKE radiator.

The following table shows the inner and outer radius for the liquid and vapour tubes :

Description	Outer Radius [mm]	Inner Radius [mm]
Loop Heat Pipes liquid tube	1.5	1.0
Loop Heat Pipes vapour tube	2.0	1.5



CARLO GAVAZZI SPACE SpA

# AMS02 - TCS

## CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°:

AMSTCS-TN-CGS-008

Ediz.:  
Issue:

1

Data:  
Date:

27/03/08

Pagina  
Page

11

di  
of

41

## 5. CAB LOOP HEAT PIPES FEM DESCRIPTION

The structure of the Loop Heat Pipes vapour tubes is modelled in the WAKE radiator FE model. It is analyzed with different runs; in this document the results are presented.

In the FE Model the Tracker Radiator (attached to the high part of the main radiators), the Trunnion bridge (utilized for the application of the loads, see chapter 6 ) and the initial part of the LHP condensers are presented. The reference document for Tracker Radiator, Trunnion bridge and WAKE radiator is RD 8.

In the following figure a view of the WAKE and Tracker radiator FE model is shown.

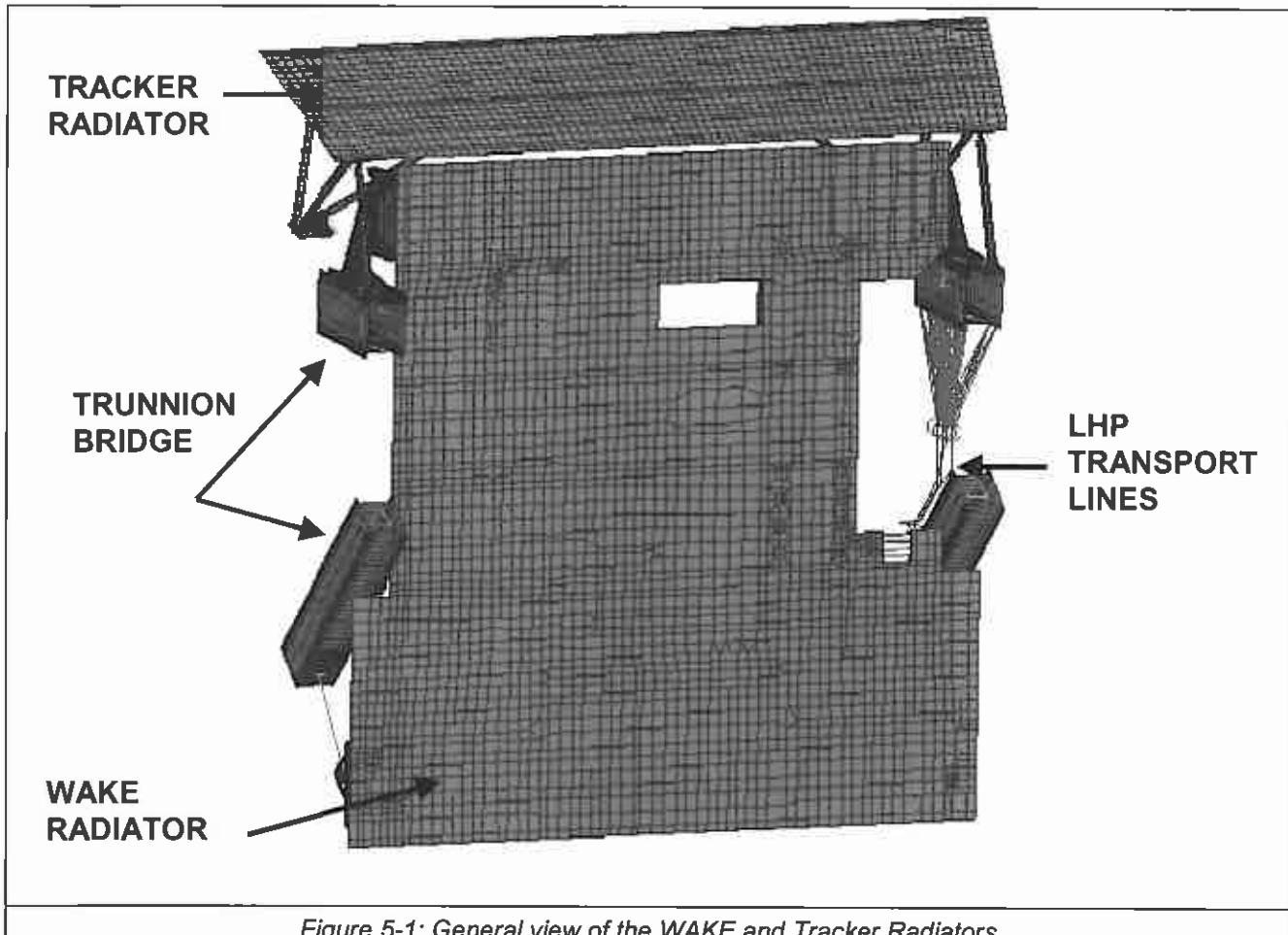


Figure 5-1: General view of the WAKE and Tracker Radiators

The CAB and the evaporators are considered rigid elements connected to the USS trunnion bridge where the bolted junction is placed. The following figure shows the CAB-trunnion fixing points.



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:

Doc N°:

AMSTCS-TN-CGS-008

Ediz.:

1

Data:

27/03/08

Issue:

Pagina

12

di

41

Page

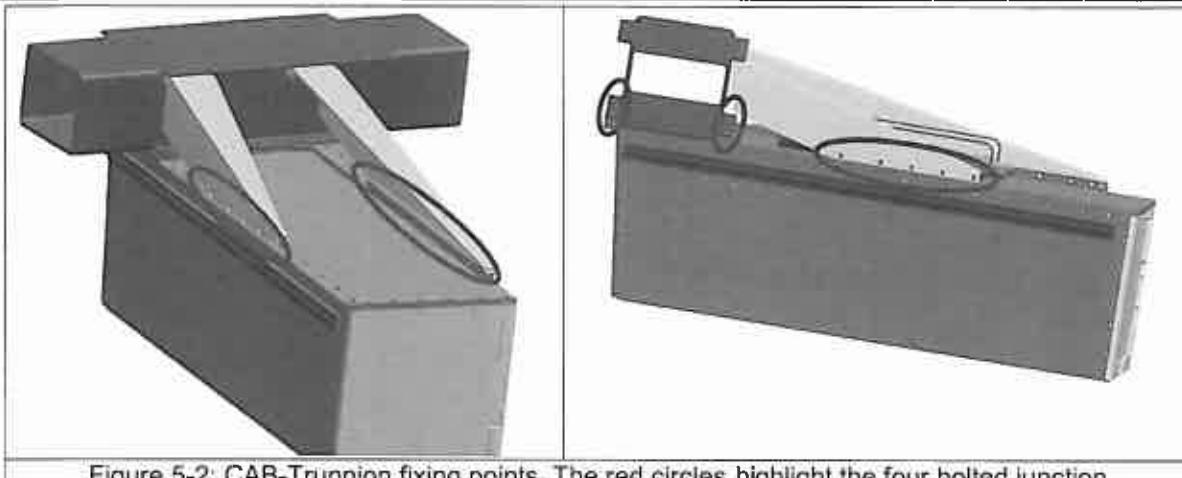
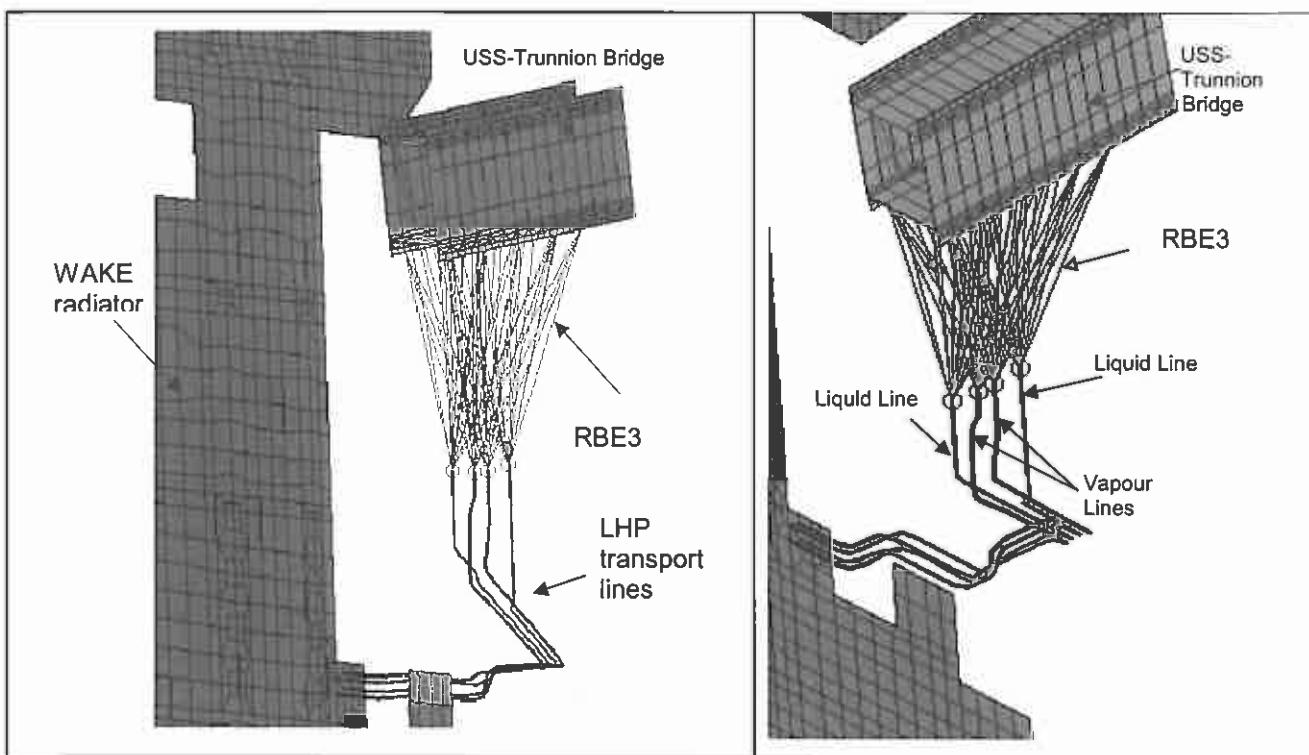


Figure 5-2: CAB-Trunnion fixing points. The red circles highlight the four bolted junction

The elements used to simulate the CAB and evaporator behaviour are RBE3 that connect the starting nodes of the LHP liquid and vapour tubes (the evaporators outputs) to the CAB-USS Trunnion fixation points. The RBE3 elements are used to avoid unrealistic stiffness effect in the structure.

An additional fixing point between each LHP transport line has been considered to avoid the pipe bumping during launch. This connection has been implemented using a rigid element RBE2 that fixes the three translations, but it allows the three rotations.

The following figures show the FEM details.





CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°:

AMSTCS-TN-CGS-008

Ediz.:  
Issue:

1

Data:  
Date: 27/03/08Pagina  
Page

13

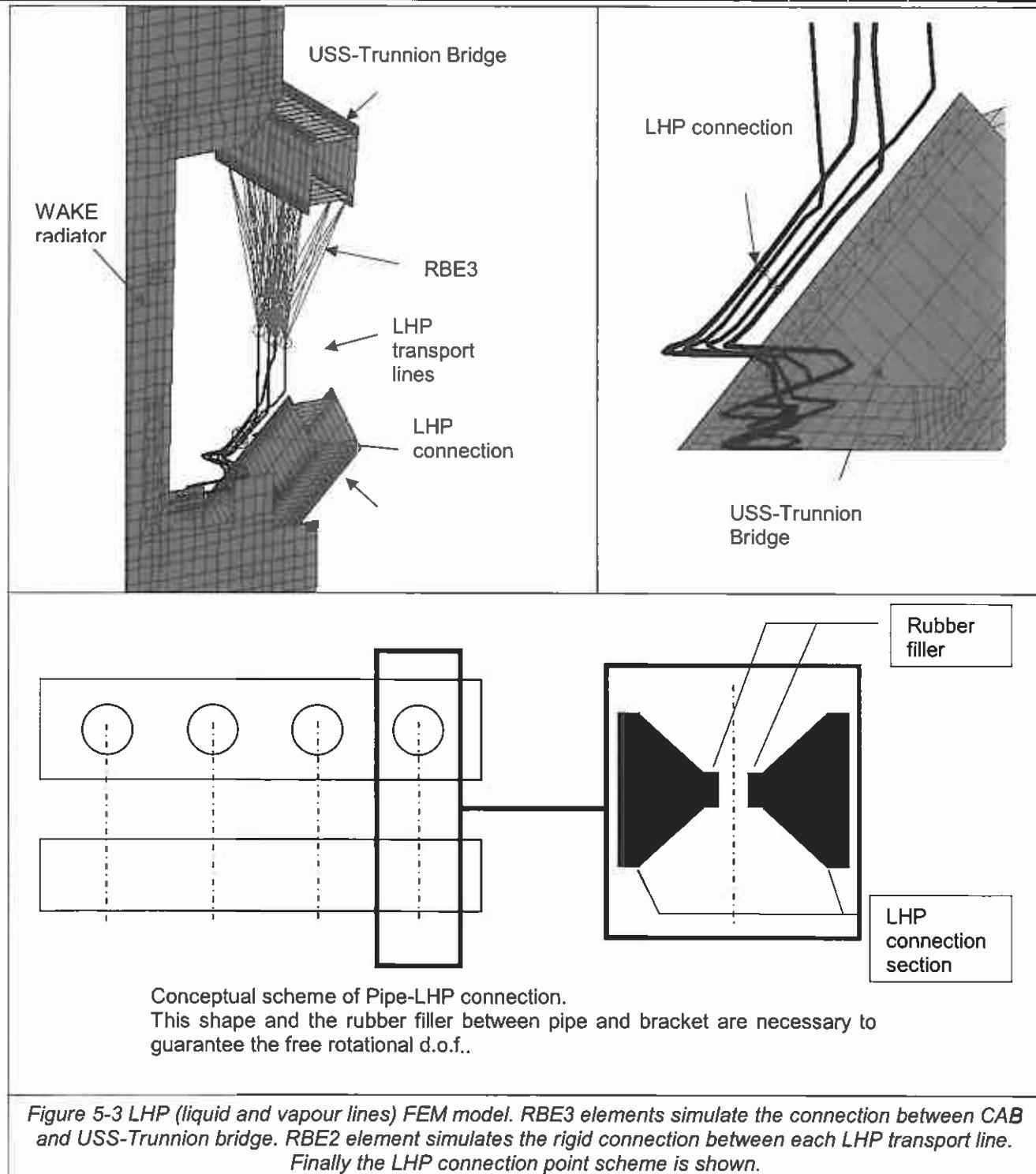
di  
of 41

Figure 5-3 LHP (liquid and vapour lines) FEM model. RBE3 elements simulate the connection between CAB and USS-Trunnion bridge. RBE2 element simulates the rigid connection between each LHP transport line.  
Finally the LHP connection point scheme is shown.

As shown in the Figure 5-3 the WAKE radiator cut out has been implemented in the FE model in order to place the LHP transport lines routing.

The LHP vapour tubes are modelled using bar elements; the following table shows the vapour tubes characteristics.



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°:

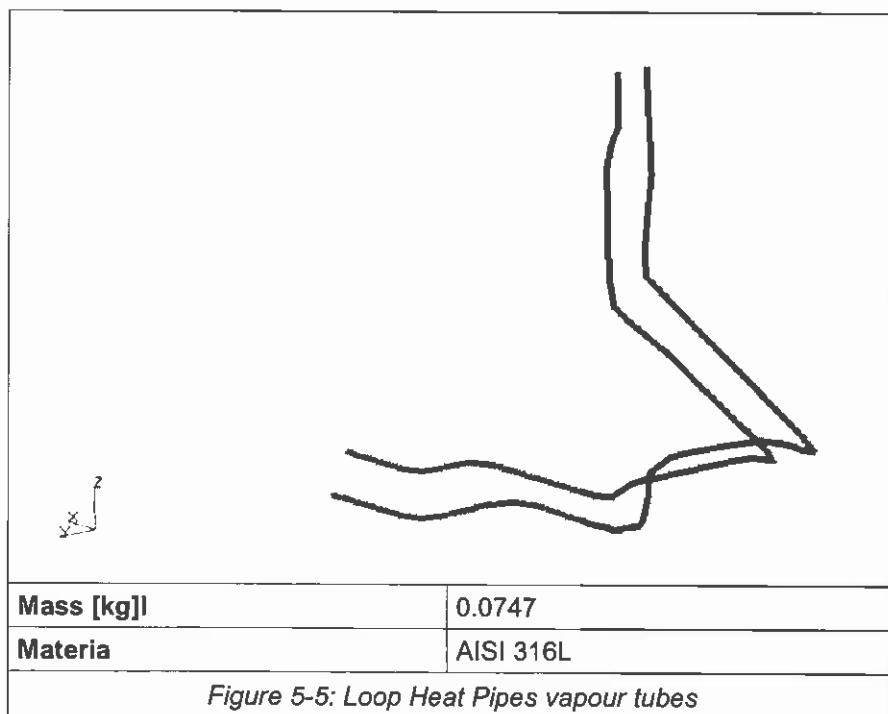
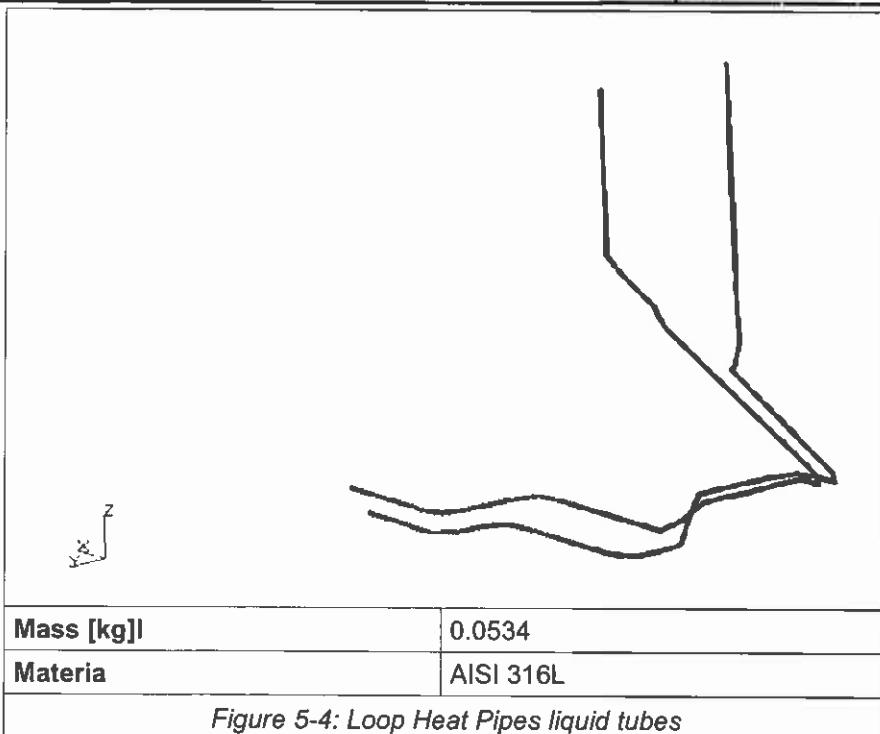
AMSTCS-TN-CGS-008

Ediz.:  
Issue:

1

Data:  
Date: 27/03/08Pagina:  
Page:

14

di  
of 41

The LHP transport lines are connected to the WAKE radiator by using the nodes coincidence; this technique is utilized to simulate the glued connection of the LHP line with the WAKE radiator.  
The following figures show the LHP vapour tubes FE model details.



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°:

AMSTCS-TN-CGS-008

Ediz.:  
Issue:

1

Data:  
Date:

27/03/08

Pagina  
Page

15

di  
of

41

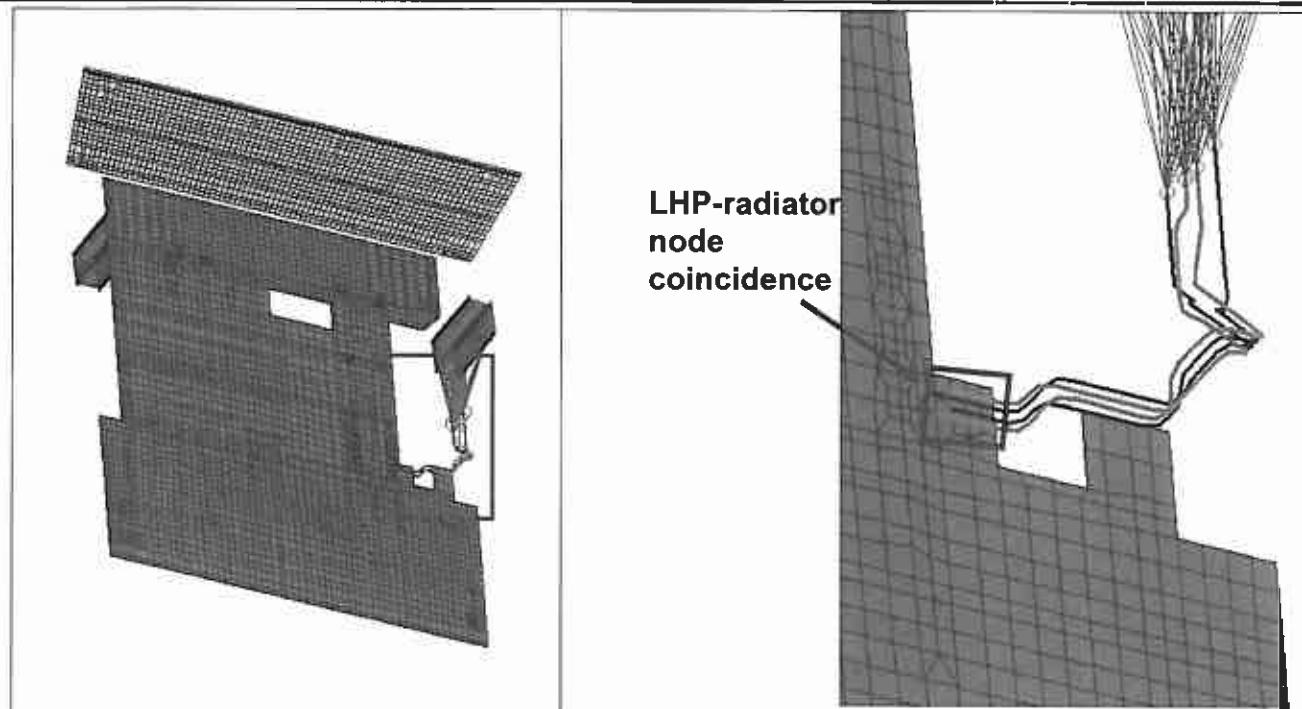


Figure 5-6: LHP transport lines-WAKE radiator fixing points. The red square highlights the node coincidence zone

The adding elements to the WAKE radiator model are reported in the following table.

LHP LIQUID AND VAPOUR TUBES	
GRID POINTS	168
ELEMENTS	168
CBAR	164
RBE3	5

Table 5-1: Model summary

## 5.1 USED SOFTWARE

The software used for FEM pre and post processing is MSC/PATRAN 2005r2.  
The software used for Finite Element analysis is MSC/NASTRAN V2005.

## 5.2 MODEL UNITS

Default FEM units (otherwise specified) are:

- Length [m]
- Mass [Kg]
- Force [N]
- Moment [Nm]
- Materials density [Kg/m<sup>3</sup>]
- Young's module [N/m<sup>2</sup>]
- Stress [N/m<sup>2</sup>]
- Displacements [m]



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

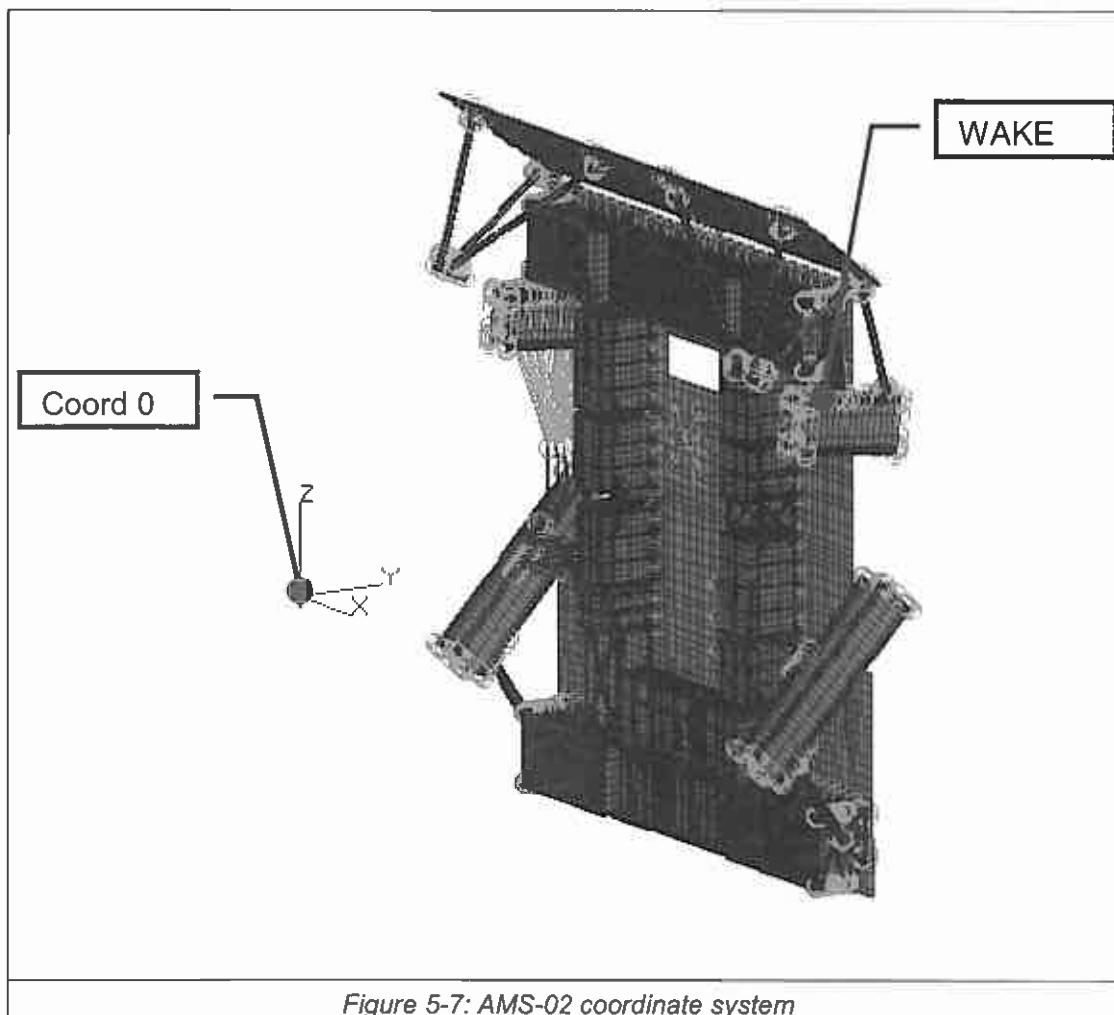
N° Doc: AMSTCS-TN-CGS-008  
Doc N°:

Ediz.: 1 Data: 27/03/08  
Issue:

Pagina 16 di 41  
Page

### 5.3 MODEL COORDINATE SYSTEM

For the WAKE Main Radiators model, the AMS-02 coordinate system (Coord 0 in Figure 5-7) is used:





CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc: AMSTCS-TN-CGS-008  
Doc N°:Ediz.: 1 Data: 27/03/08  
Issue:Pagina 17 di 41  
Page

Next image shows the WAKE Main Radiators FE model dimensions and position with respect to the AMS coordinate system.

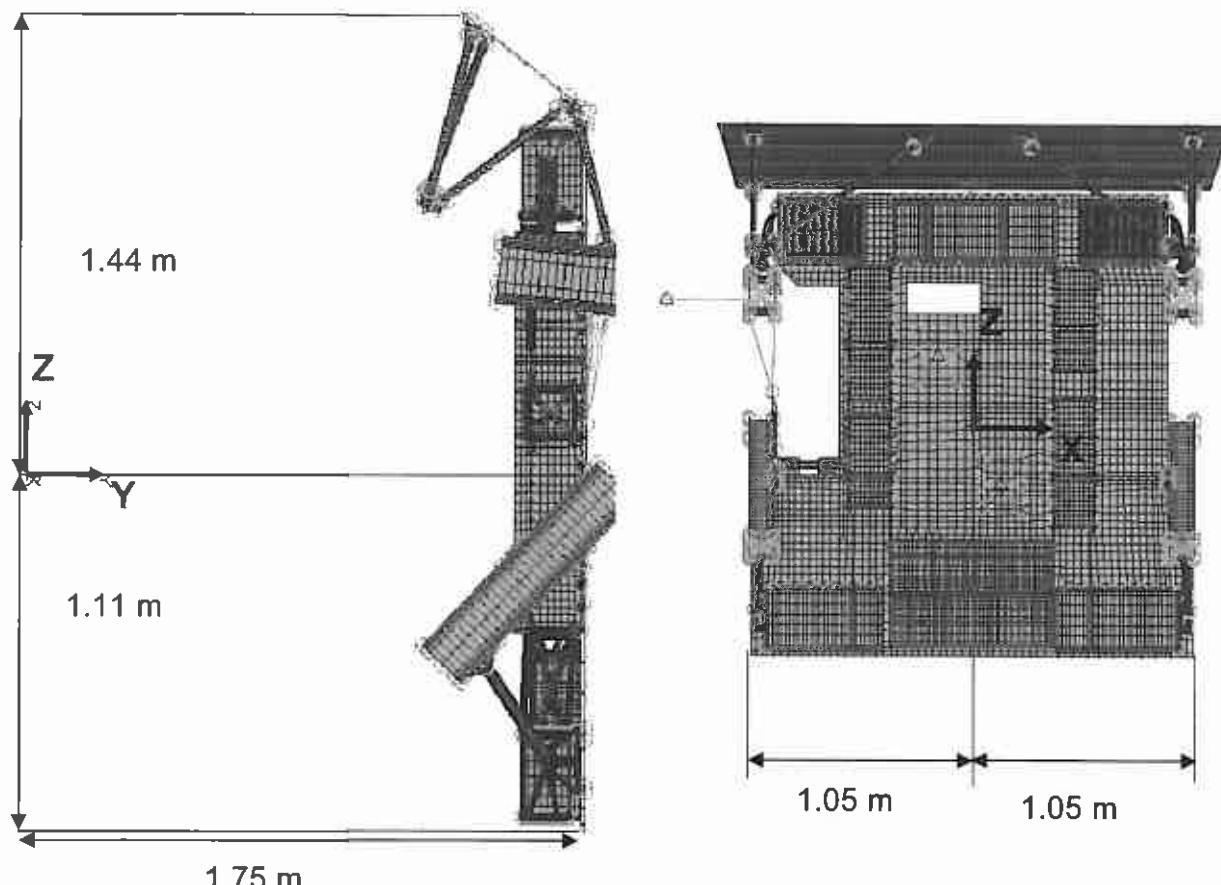


Figure 5-8: Main Radiators dimensions

 <b>CARLO GAVAZZI SPACE SpA</b>	<b>AMS02 - TCS</b>	N° Doc: Doc N°: <b>AMSTCS-TN-CGS-008</b>  Ediz.: Issue: <b>1</b> Data: Date: <b>27/03/08</b>
	CAB TCS STRUCTURAL ANALYSIS REPORT	Pagina Page <b>18</b> di of <b>41</b>

## 5.4 MODEL MATERIALS

In the following table is reported:

- properties of each material
- items material
- corresponding NASTRAN card

### 5.4.1 STAINLESS STEEL AISI 316L

<b>AISI 316 STAINLESS STEEL</b>		
Source	Vendor datasheet	
Specification	ASTM A-632-04	
Condition	Annealed	
Form	Hydraulic Tubing	
<b>Mechanical Properties</b>		
	[MPa]	[ksi]
Ftu	557.00	80.79
Fty	303.00	43.95
Fcy	303.00	43.95
E	193053.25	28000
<b>Physical Properties</b>		
	[kg/m <sup>3</sup> ]	[lb/in <sup>3</sup> ]
ρ	8000.00	0.347
v	0.28	

*Table 5-2: AISI 316L properties*

NASTRAN CARD:	MAT1	1	1.93+11	7.539+10.28	8000.	5.193-5	293.15
USED ON ITEMS:	LHP TRANSPORT LINES						

*Table 5-3: AISI 316L in FE model*



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc: AMSTCS-TN-CGS-008  
Doc N°:Ediz.: 1 Data: 27/03/08  
Issue:Pagina 19 di 41  
Page

### 5.5 MODEL BOUNDARY CONDITIONS

In the following figures the constrain condition for the WAKE Radiator is presented: the Radiator is connected through the brackets (Top, Mid and Lower) to the Trunion Bridges. These are constrained with 8 SPC (6 DoF) connected with the RBE2. Other 2 SPC (6 DoF) are used to constrain the tracker radiator.

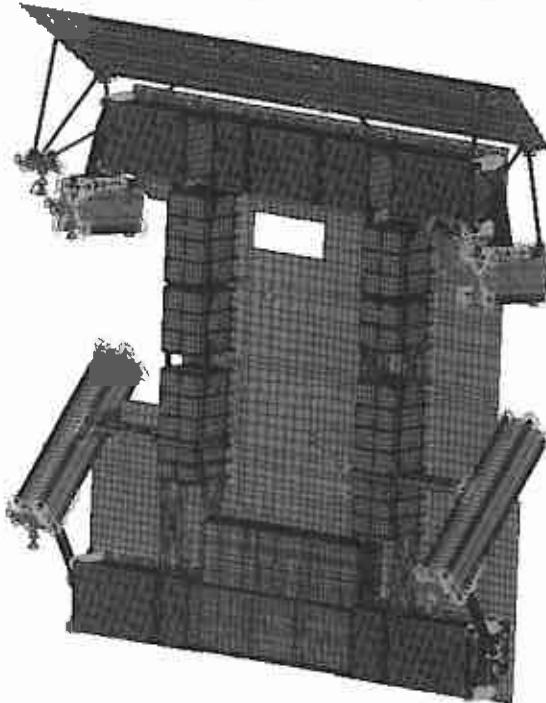


Figure 5-9: Model boundary conditions for WAKE Radiator

 <b>CARLO GAVAZZI</b> <b>CARLO GAVAZZI SPACE SpA</b>	<h1 style="text-align: center;">AMS02 - TCS</h1> <p style="text-align: center;">CAB TCS STRUCTURAL ANALYSIS REPORT</p>	N° Doc: Doc N°: <b>AMSTCS-TN-CGS-008</b> Ediz.: <b>1</b> Data: <b>27/03/08</b> Issue: Pagina Page <b>20</b> di <b>41</b>

## 5.6 MODEL MASS BUDGET

The following table shows the mass budget of the WAKE radiator with the addition of LHP vapour tubes  
The reference document for the WAKE radiator mass budget is the RD 8.

The mass of the model is without any contingency.

SUBSYSTEM	EQUIPMENT	COMPONENT	MASS [Kg]	TOTAL MASS	REMARKS
WAKE RADIATOR		TOT. WAKE [RD8]	343.50	343.50	
		LHP TUBES	0.1281	0.1281	
TOT. UPDATED WAKE				343.6281	

Table 5-4: WAKE Radiator updated mass budget

## 5.7 MODEL CHECK FOR CAB TCS FE MODEL

### 5.7.1 FREE-FREE AND HARDMOUNTED MODES

MATHEMATICAL MODEL VERIFICATION RESULTS																																																																																																																																																									
MASS PROPERTIES, FREE-FREE MODES, HARDMOUNTED MODES																																																																																																																																																									
<b>MODEL FILE NAMES:</b> AMS_WAKE_CAB_LHP_260308.bdf																																																																																																																																																									
<b>RUN FILE NAMES:</b> AMS_WAKE_CAB_LHP_260308_MODAL_FREE_FREE.dat; param.blk, EFFMASSA.V707																																																																																																																																																									
<b>MODEL UNITS:</b> Length=m, mass=Kg, density=Kg/m^3, Young mod.=N/m^2, Stress=N/m^2, Deformation=m, Strain En=N*m=Joule.																																																																																																																																																									
<b>PARAMETERS:</b> PARAM,POST,0 PARAM,PRTMAXIM,YES PARAM,AUTOSPC,YES PARAM,COUPMASS,1		PARAM,GRDPNT,0 PARAM,WTMASS,1. PARAM,K6ROT,1. PARAM,PRGPST,NO PARAM,NOCOMPS,0																																																																																																																																																							
<b>MASS PROPERTIES</b>	<table style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th style="text-align: left;">O U T P U T   F R O M   G R I D   P O I N T</th> <th style="text-align: left;">W E I G H T   G E N E R A T O R</th> <th style="text-align: left;">R E F E R E N C E   P O I N T =</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">0</td> <td style="text-align: center;">M O</td> <td style="text-align: center;">0</td> </tr> <tr> <td style="text-align: center;">*</td> <td style="text-align: center;">3.800601E+02 -1.228574E-17 4.499131E-17 1.058656E-16 5.372408E+00 -6.315227E+02 *</td> <td></td> </tr> <tr> <td style="text-align: center;">*</td> <td style="text-align: center;">-1.228574E-17 3.800601E+02 7.886615E-17 -5.372408E+00 -4.504925E-17 -2.033308E+01 *</td> <td></td> </tr> <tr> <td style="text-align: center;">*</td> <td style="text-align: center;">4.499131E-17 7.886615E-17 3.800601E+02 6.315227E+02 2.033308E+01 -6.235422E-17 *</td> <td></td> </tr> <tr> <td style="text-align: center;">*</td> <td style="text-align: center;">1.058656E-16 -5.372408E+00 6.315227E+02 1.276917E+03 3.815973E+01 1.586469E+01 *</td> <td></td> </tr> <tr> <td style="text-align: center;">*</td> <td style="text-align: center;">5.372408E+00 -4.504925E-17 2.033308E+01 3.815973E+01 3.960107E+02 -7.954353E+00 *</td> <td></td> </tr> <tr> <td style="text-align: center;">*</td> <td style="text-align: center;">-6.315227E+02 -2.033308E+01 -6.235422E-17 1.586469E+01 -7.954353E+00 1.225711E+03 *</td> <td></td> </tr> <tr> <td style="text-align: center;">S</td> <td style="text-align: center;">* 1.000000E+00 0.000000E+00 0.000000E+00 *</td> <td></td> </tr> <tr> <td style="text-align: center;">*</td> <td style="text-align: center;">* 0.000000E+00 1.000000E+00 0.000000E+00 *</td> <td></td> </tr> <tr> <td style="text-align: center;">*</td> <td style="text-align: center;">* 0.000000E+00 0.000000E+00 1.000000E+00 *</td> <td></td> </tr> <tr> <td colspan="6" style="text-align: center;">DIRECTION</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">MASS AXIS SYSTEM (S)      MASS      X-C.G.      Y-C.G.      Z-C.G.</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">X      3.800601E+02      2.785497E-19 1.661639E+00 1.413568E-02</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">Y      3.800601E+02      -5.349966E-02 -1.185319E-19 1.413568E-02</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">Z      3.800601E+02      -5.349966E-02 1.661639E+00 -1.640641E-19</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">I (S)</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">* 2.274785E+02 -4.373478E+00 -1.557727E+01 *</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">* -4.373478E+00 3.948469E+02 -9.726518E-01 *</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">* -1.557727E+01 -9.726518E-01 1.752605E+02 *</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">I (Q)</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">* 1.709664E+02 * * *</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">* * 2.316496E+02 * *</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">* * 3.949698E+02 *</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">Q</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">* 2.658067E-01 -9.636568E-01 2.668945E-02 *</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">* -1.004278E-03 2.740858E-02 9.996238E-01 *</td><td></td></tr> <tr> <td colspan="6" style="text-align: center;">* -9.640259E-01 -2.657335E-01 6.317602E-03 *</td><td></td></tr> </tbody></table>	O U T P U T   F R O M   G R I D   P O I N T	W E I G H T   G E N E R A T O R	R E F E R E N C E   P O I N T =	0	M O	0	*	3.800601E+02 -1.228574E-17 4.499131E-17 1.058656E-16 5.372408E+00 -6.315227E+02 *		*	-1.228574E-17 3.800601E+02 7.886615E-17 -5.372408E+00 -4.504925E-17 -2.033308E+01 *		*	4.499131E-17 7.886615E-17 3.800601E+02 6.315227E+02 2.033308E+01 -6.235422E-17 *		*	1.058656E-16 -5.372408E+00 6.315227E+02 1.276917E+03 3.815973E+01 1.586469E+01 *		*	5.372408E+00 -4.504925E-17 2.033308E+01 3.815973E+01 3.960107E+02 -7.954353E+00 *		*	-6.315227E+02 -2.033308E+01 -6.235422E-17 1.586469E+01 -7.954353E+00 1.225711E+03 *		S	* 1.000000E+00 0.000000E+00 0.000000E+00 *		*	* 0.000000E+00 1.000000E+00 0.000000E+00 *		*	* 0.000000E+00 0.000000E+00 1.000000E+00 *		DIRECTION							MASS AXIS SYSTEM (S)      MASS      X-C.G.      Y-C.G.      Z-C.G.							X      3.800601E+02      2.785497E-19 1.661639E+00 1.413568E-02							Y      3.800601E+02      -5.349966E-02 -1.185319E-19 1.413568E-02							Z      3.800601E+02      -5.349966E-02 1.661639E+00 -1.640641E-19							I (S)							* 2.274785E+02 -4.373478E+00 -1.557727E+01 *							* -4.373478E+00 3.948469E+02 -9.726518E-01 *							* -1.557727E+01 -9.726518E-01 1.752605E+02 *							I (Q)							* 1.709664E+02 * * *							* * 2.316496E+02 * *							* * 3.949698E+02 *							Q							* 2.658067E-01 -9.636568E-01 2.668945E-02 *							* -1.004278E-03 2.740858E-02 9.996238E-01 *							* -9.640259E-01 -2.657335E-01 6.317602E-03 *						
O U T P U T   F R O M   G R I D   P O I N T	W E I G H T   G E N E R A T O R	R E F E R E N C E   P O I N T =																																																																																																																																																							
0	M O	0																																																																																																																																																							
*	3.800601E+02 -1.228574E-17 4.499131E-17 1.058656E-16 5.372408E+00 -6.315227E+02 *																																																																																																																																																								
*	-1.228574E-17 3.800601E+02 7.886615E-17 -5.372408E+00 -4.504925E-17 -2.033308E+01 *																																																																																																																																																								
*	4.499131E-17 7.886615E-17 3.800601E+02 6.315227E+02 2.033308E+01 -6.235422E-17 *																																																																																																																																																								
*	1.058656E-16 -5.372408E+00 6.315227E+02 1.276917E+03 3.815973E+01 1.586469E+01 *																																																																																																																																																								
*	5.372408E+00 -4.504925E-17 2.033308E+01 3.815973E+01 3.960107E+02 -7.954353E+00 *																																																																																																																																																								
*	-6.315227E+02 -2.033308E+01 -6.235422E-17 1.586469E+01 -7.954353E+00 1.225711E+03 *																																																																																																																																																								
S	* 1.000000E+00 0.000000E+00 0.000000E+00 *																																																																																																																																																								
*	* 0.000000E+00 1.000000E+00 0.000000E+00 *																																																																																																																																																								
*	* 0.000000E+00 0.000000E+00 1.000000E+00 *																																																																																																																																																								
DIRECTION																																																																																																																																																									
MASS AXIS SYSTEM (S)      MASS      X-C.G.      Y-C.G.      Z-C.G.																																																																																																																																																									
X      3.800601E+02      2.785497E-19 1.661639E+00 1.413568E-02																																																																																																																																																									
Y      3.800601E+02      -5.349966E-02 -1.185319E-19 1.413568E-02																																																																																																																																																									
Z      3.800601E+02      -5.349966E-02 1.661639E+00 -1.640641E-19																																																																																																																																																									
I (S)																																																																																																																																																									
* 2.274785E+02 -4.373478E+00 -1.557727E+01 *																																																																																																																																																									
* -4.373478E+00 3.948469E+02 -9.726518E-01 *																																																																																																																																																									
* -1.557727E+01 -9.726518E-01 1.752605E+02 *																																																																																																																																																									
I (Q)																																																																																																																																																									
* 1.709664E+02 * * *																																																																																																																																																									
* * 2.316496E+02 * *																																																																																																																																																									
* * 3.949698E+02 *																																																																																																																																																									
Q																																																																																																																																																									
* 2.658067E-01 -9.636568E-01 2.668945E-02 *																																																																																																																																																									
* -1.004278E-03 2.740858E-02 9.996238E-01 *																																																																																																																																																									
* -9.640259E-01 -2.657335E-01 6.317602E-03 *																																																																																																																																																									

  |  |  |  |  |  |



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

Nº Doc:  
Doc N°: AMSTCS-TN-CGS-008Ediz.: 1 Data: 27/03/08  
Issue:

## CAB TCS STRUCTURAL ANALYSIS REPORT

Pagina 21 di 41  
Page 21 of 41

	MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANES	CYCLES	GENERALIZED	GENERALIZED
						MASS	STIFFNESS
RIGID BODY NORMAL MODE CHECK	1	1	-3.726284E-07	6.104330E-04	9.715342E-05	1.000000E+00	-3.726284E-07
	2	2	-2.336888E-07	4.834136E-04	7.693767E-05	1.000000E+00	-2.336888E-07
	3	3	-1.526963E-07	3.907637E-04	6.219198E-05	1.000000E+00	-1.526963E-07
	4	4	1.086924E-07	3.296853E-04	5.247104E-05	1.000000E+00	1.086924E-07
	5	5	2.994549E-07	5.472247E-04	8.709352E-05	1.000000E+00	2.994549E-07
	6	6	4.003709E-07	6.327486E-04	1.007051E-04	1.000000E+00	4.003709E-07
	7	7	8.361788E+01	9.144281E+00	1.455358E+00	1.000000E+00	8.361788E+01
HARDMOUNTED NORMAL MODE CHECK	1	1	1.795547E+04	1.339980E+02	2.132644E+01	1.000000E+00	1.795547E+04
	2	2	2.726259E+04	1.651139E+02	2.627869E+01	1.000000E+00	2.726259E+04
	3	3	3.515308E+04	1.874915E+02	2.984020E+01	1.000000E+00	3.515308E+04
	4	4	4.040232E+04	2.010033E+02	3.199067E+01	1.000000E+00	4.040232E+04
	5	5	4.474501E+04	2.115302E+02	3.366607E+01	1.000000E+00	4.474501E+04
	6	6	4.587601E+04	2.141869E+02	3.408690E+01	1.000000E+00	4.587601E+04
	7	7	5.789539E+04	2.406146E+02	3.829500E+01	1.000000E+00	5.789539E+04
	8	8	1.122695E+05	3.350663E+02	5.332746E+01	1.000000E+00	1.122695E+05
	9	9	1.341313E+05	3.662394E+02	5.828861E+01	1.000000E+00	1.341313E+05
	10	10	1.408105E+05	3.752472E+02	5.972245E+01	1.000000E+00	1.408105E+05

Table 5-5: FEM mass properties, free-free modes, hardmounted modes



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°: AMSTCS-TN-CGS-008Ediz.:  
Issue: 1 Data:  
Date: 27/03/08Pagina  
Page 22 di  
of 41

## 5.7.2 1 G CHECK

MATHEMATICAL MODEL VERIFICATION RESULTS 1g CHECK																			
MODEL FILE NAMES : AMS_WAKE_CAB_LHP_260308.bdf																			
RUN FILE NAMES :		AMS_WAKE_CAB_LHP_260308_STATIC_1G.dat, WAKE_LHP_subcases_1gchk.blk,																	
PARAMETERS:		PARAM,GRDPNT,0 PARAM,POST,0 PARAM,PRTMAXIM,YES PARAM,AUTOSPC,YES PARAM,COUPMASS,1																	
PARAM,WTMASS,1. PARAM,K6ROT,1. PARAM,PRGPST,NO PARAM,NOCOMPS,0																			
0																			
SUBCASE/ DAREA ID																			
LOAD																			
TYPE																			
T1 T2 T3 R1 R2 R3																			
0 10001 FX 3.727991E+03 ---- ---- ---- 5.227995E+01 -6.194364E+03																			
FY ---- -1.371583E-16 2.111097E-07 ---- -6.314169E-10																			
FZ ---- 4.258671E-16 -2.111097E-07 -9.502832E-10 ----																			
MX ---- ---- -1.412753E-20 ----																			
MY ---- ---- 1.880991E-01 ----																			
MZ ---- ---- -2.029304E-01																			
TOTALS 3.727991E+03 -1.371583E-16 4.258671E-16 -1.413406E-20 5.246805E+01 -6.194567E+03																			
0 10002 FX -1.363486E-16 ---- ---- -2.111097E-07 -1.401884E-07																			
FY ---- 3.727991E+03 ---- -5.228000E+01 -1.401884E-07																			
FZ ---- 7.078474E-16 4.620860E-05 2.111097E-07 ----																			
MX ---- ---- -1.880991E-01 ----																			
MY ---- ---- -7.327625E-21 ----																			
MZ ---- ---- -1.466425E-01																			
TOTALS -1.363486E-16 3.727991E+03 7.078474E-16 -5.246805E+01 -7.332129E-21 -1.990799E+02																			
0 10003 FX 4.2586022E-16 ---- ---- 3.178717E-07 2.111097E-07																			
FY ---- 7.805229E-16 6.960604E-05 2.111097E-07																			
FZ ---- 3.727991E+03 6.194364E+03 1.989332E+02 ----																			
MX ---- 2.029304E-01 ----																			
MY ---- ---- 1.466425E-01 ----																			
MZ ---- ---- -3.734517E-20																			
TOTALS 4.2586022E-16 7.805229E-16 3.727991E+03 6.194567E+03 1.990799E+02 -3.734806E-20																			
SPCFORCE RESULTANT																			
0																			
SUBCASE/ DAREA ID																			
LOAD																			
TYPE																			
T1 T2 T3 R1 R2 R3																			
0 10001 FX -3.727991E+03 ---- ---- -1.419236E+02 6.103333E+03																			
FY ---- -6.600970E-09 6.768677E+00 ----																			
FZ ---- 1.501093E-09 -8.317255E+00 2.380112E+02																			
MX ---- 1.548578E+00 ----																			
MY ---- ---- -1.485557E+02 ----																			
MZ ---- ---- -1.498128E+01																			
TOTALS -3.727991E+03 -6.600970E-09 1.501093E-09 -1.192093E-07 -5.246805E+01 6.194567E+03																			
0 10002 FX 6.806431E-10 ---- ---- -1.079767E+02 6.103913E+00																			
FY ---- -3.727991E+03 -5.205121E+01 ----																			
FZ ---- -1.988758E-08 5.759569E+01 1.181342E+02																			
MX ---- 4.692357E+01 ----																			
MY ---- ---- -1.015750E+01 ----																			
MZ ---- ---- 9.007046E+01																			
TOTALS 6.806431E-10 -3.727991E+03 -1.988758E-08 5.246805E+01 -1.907349E-06 1.990799E+02																			
0 10003 FX -6.011192E-11 ---- ---- -1.553024E+02 -6.255392E+00																			
FY ---- 6.233726E-09 -3.767000E+01 ----																			
FZ ---- -3.727991E+03 -6.127150E+03 6.177354E+01																			
MX ---- -2.974723E+01 ----																			
MY ---- ---- -1.055510E+02 ----																			
MZ ---- ---- 1.384900E+01																			
TOTALS -6.011192E-11 6.233726E-09 -3.727991E+03 -6.194567E+03 -1.990799E+02 4.768372E-07																			
EPSILON																			
LOAD SEQ. NO. EPSILON EXTERNAL WORK																			
1 -1.5975862E-12 1.5127064E-01																			
2 -5.1446727E-13 5.0051391E-01																			
3 -2.4290999E-12 3.1165689E-01																			

Table 5-6: FEM 1g check



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

## CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°:

AMSTCS-TN-CGS-008

Ediz.:  
Issue:

1

Data:  
Date: 27/03/08Pagina  
Page

23

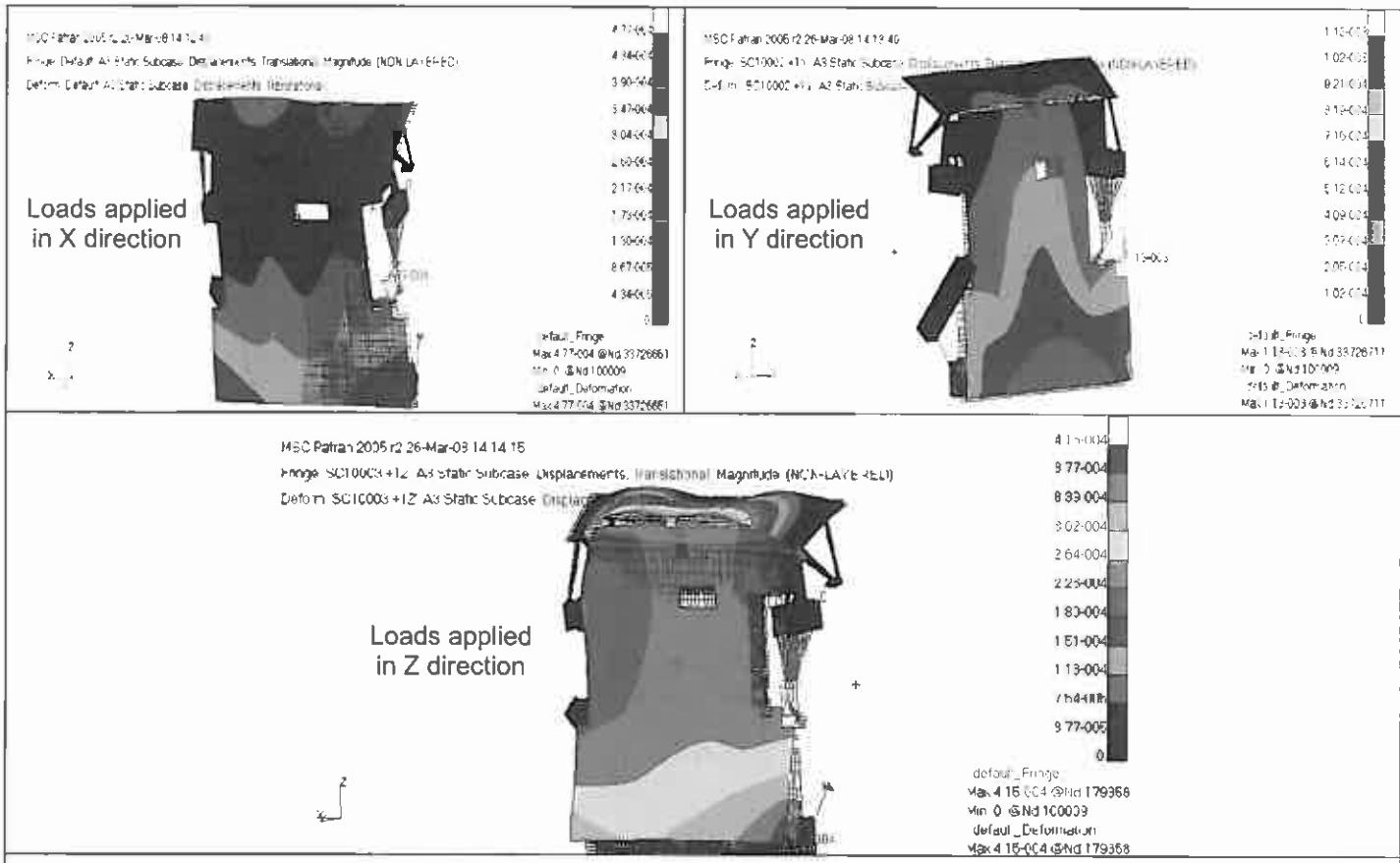
di  
of 41

Figure 5-10: 1G check analysis run results for CAB TCS side



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°:

AMSTCS-TN-CGS-008

Ediz.:  
Issue:

1

Data:  
Date: 27/03/08Pagina  
Page

24

di  
of 41

## 5.7.3 STRAIN ENERGY CHECK

MATHEMATICAL MODEL VERIFICATION RESULTS  
STRAIN ENERGY CHECK

## MODEL FILE NAMES :

AMS\_WAKE\_CAB\_LHP\_260308.bdf

## RUN FILE NAMES

AMS\_WAKE\_CAB\_LHP\_260308\_STRAIN\_ENERGY.dat, param.blk

## COMAND:

GROUNDCHECK(SET=ALL,THRESH=1.E-3,DATAREC=YES,1.E-3) = YES

## PARAMETERS:

PARAM,POST,0

PARAM,PRTMAXIM,YES

PARAM,AUTOSPC,YES

PARAM,COUPMASS,1

PARAM,GRDPNT,0

PARAM,WTMASS,1.

PARAM,K6ROT,1.

PARAM,PRGPST,NO

PARAM,NOCOMPS,0

STRAIN  
ENERGY CHECK  
[J]RESULTS OF RIGID BODY CHECKS OF MATRIX KGG (G-SET) FOLLOW:  
PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF 1.000000E-03

DIRECTION STRAIN ENERGY PASS/FAIL

1	1.518065E-05	PASS
2	1.868980E-05	PASS
3	4.100486E-05	PASS
4	9.585273E-05	PASS
5	3.988781E-05	PASS
6	8.762105E-05	PASS

RESULTS OF RIGID BODY CHECKS OF MATRIX KNN (N-SET) FOLLOW:  
PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF 1.000000E-03

DIRECTION STRAIN ENERGY PASS/FAIL

1	2.120990E-05	PASS
2	2.809238E-05	PASS
3	4.132698E-05	PASS
4	7.506558E-05	PASS
5	5.653784E-05	PASS
6	4.357303E-05	PASS

RESULTS OF RIGID BODY CHECKS OF MATRIX KNN+AUTO (N+AUTOSPC-SET) FOLLOW:  
PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF 1.000000E-03

DIRECTION STRAIN ENERGY PASS/FAIL

1	2.120990E-05	PASS
2	2.809238E-05	PASS
3	4.132698E-05	PASS
4	7.506558E-05	PASS
5	5.653784E-05	PASS
6	4.357303E-05	PASS

RESULTS OF RIGID BODY CHECKS OF MATRIX KFF (F-SET) FOLLOW:  
PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF 1.000000E-03

DIRECTION STRAIN ENERGY PASS/FAIL

1	2.120990E-05	PASS
2	2.809238E-05	PASS
3	4.132698E-05	PASS
4	7.506558E-05	PASS
5	5.653784E-05	PASS
6	4.357303E-05	PASS

Table 5-7: FEM Strain Energy check



CARLO GAVAZZI SPACE SpA

# AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc: AMSTCS-TN-CGS-008  
Doc N°:Ediz.: 1 Data: 27/03/08  
Issue:Pagina 25 di 41  
Page

## 6. DIMENSIONING LOADS

The dimensioning loads are described in the RD 8.

The following table shows the considered load cases summary.

Load Case Summary					
Load Case	Inertial	Enf. Displ.	Acoustic	EVA Load	Remarks
1001-1064	Yes	Yes	Yes		Launch config.
2001-2064	Yes	Yes			Launch config.

Table 6-1: Applied set of load cases

 <b>CARLO GAVAZZI SPACE SpA</b>	<b>AMS02 - TCS</b>	N° Doc: Doc N°:	<b>AMSTCS-TN-CGS-008</b>
		Ediz.: Issue:	1 Data: Date: <b>27/03/08</b>
	CAB TCS STRUCTURAL ANALYSIS REPORT	Pagina Page	<b>26</b> di of <b>41</b>

## 7. DIMENSIONING RULES

### 7.1 SAFETY FACTORS

TCS CAB Loop Heat Pipes have to show positive MoS applying the following SF:

SAFETY FACTORS	Yield	Ultimate
<b>Metallic structures</b>	1.25	2.0

*Table 7-1: Safety Factors for structure*

### 7.2 TEMPERATURE DERATING FACTOR

For all the material the temperature degradation factor is considered, as per RD 1 at 60°C (140°F) (landing temperature) the worst temperature degradation factor for the material is 6% with respect to the material nominal strength allowable. This temperature degradation factor is applied to all the material.

### 7.3 MARGINS OF SAFETY FOR STRUCTURE

The MoS is defined as:

$$MoS_Y = \frac{\sigma_y}{SF_Y \cdot \sigma_{Load}} - 1.0 \quad \text{for the yield strength, and}$$

$$MoS_U = \frac{\sigma_u}{SF_U \cdot \sigma_{Load}} - 1.0 \quad \text{for the ultimate strength, where:}$$

- $\sigma_y$  the yield strength of the material,
- $\sigma_u$  the ultimate strength of the material,
- $SF_Y$  the safety factor for yield strength,
- $SF_U$  the safety factor for ultimate strength,
- $\sigma_{Load}$  the maximum Von Mises equivalent stress due to external loads.

The MoS for stresses indicates the amount by which the allowable stress, defined by the material characteristics, exceeds the actual stress due to the applied loads, taking into account the applicable SF, defined in Chapter 7.1 . It is required that MoS are positive for all load cases, for all structural elements.



CARLO GAVAZZI SPACE SpA

# AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

Nº Doc:  
Doc N°: AMSTCS-TN-CGS-008Ediz.:  
Issue: 1 Data:  
Date: 27/03/08Pagina  
Page 27 di  
of 41

## 8. DYNAMIC ANALYSIS

In this section, results in terms of frequencies, mode shapes and effective masses are included.

### 8.1 DYNAMIC ANALYSIS FOR CAB TCS

In this section, results in terms of frequencies, mode shapes and effective masses are included.

#### 8.1.1 EIGENFREQUENCIES AND MODE SHAPES FOR CAB TCS

In the following tables the first twenty modes of the constrained CAB TCS system are shown. The CAB TCS radiator modal behaviour is similar to the TCS WAKE radiator without CAB LHP and the cut out described in RD8.

MODE	FREQ [Hz]	EFF. MASS X [Kg]	EFF. MASS Y [Kg]	EFF. MASS Z [Kg]	EFF. MASS X [%]	EFF. MASS Y [%]	EFF. MASS Z [%]
1	21.33	0.310	127.139	39.502	<5%	33.45%	10.39%
2	26.28	0.042	0.037	0.031	<5%	<5%	<5%
3	29.84	20.632	1.138	0.555	5.43%	<5%	<5%
4	31.99	35.094	0.040	2.235	9.23%	<5%	<5%
5	33.67	0.082	112.577	0.014	<5%	29.62%	<5%
6	34.09	0.860	6.695	41.075	<5%	<5%	10.81%
7	38.30	0.468	32.865	189.324	<5%	8.65%	49.81%
8	53.33	66.845	0.015	0.066	17.59%	<5%	<5%
9	58.29	72.814	0.110	0.008	19.16%	<5%	<5%
10	59.72	14.132	0.032	3.652	<5%	<5%	<5%
11	60.47	13.340	0.083	1.226	<5%	<5%	<5%
12	63.17	1.559	2.639	0.660	<5%	<5%	<5%
13	63.41	0.607	0.281	0.046	<5%	<5%	<5%
14	67.01	0.000	0.005	0.003	<5%	<5%	<5%
15	70.72	41.455	0.015	0.082	10.91%	<5%	<5%
16	72.03	0.003	0.000	0.001	<5%	<5%	<5%
17	78.51	0.001	0.114	0.001	<5%	<5%	<5%
18	79.44	0.002	0.029	0.004	<5%	<5%	<5%
19	79.54	0.012	0.006	0.002	<5%	<5%	<5%
20	79.67	0.000	0.000	0.003	<5%	<5%	<5%

Table 8-1: CAB TCS natural frequencies



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°:

AMSTCS-TN-CGS-008

Ediz.:  
Issue:

1

Data:  
Date:

27/03/08

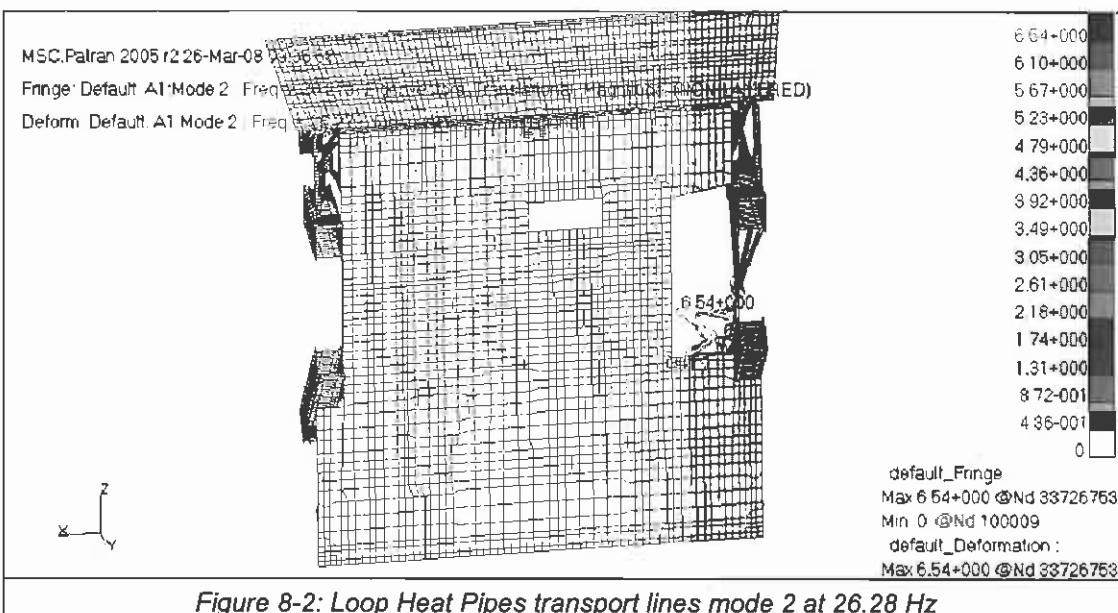
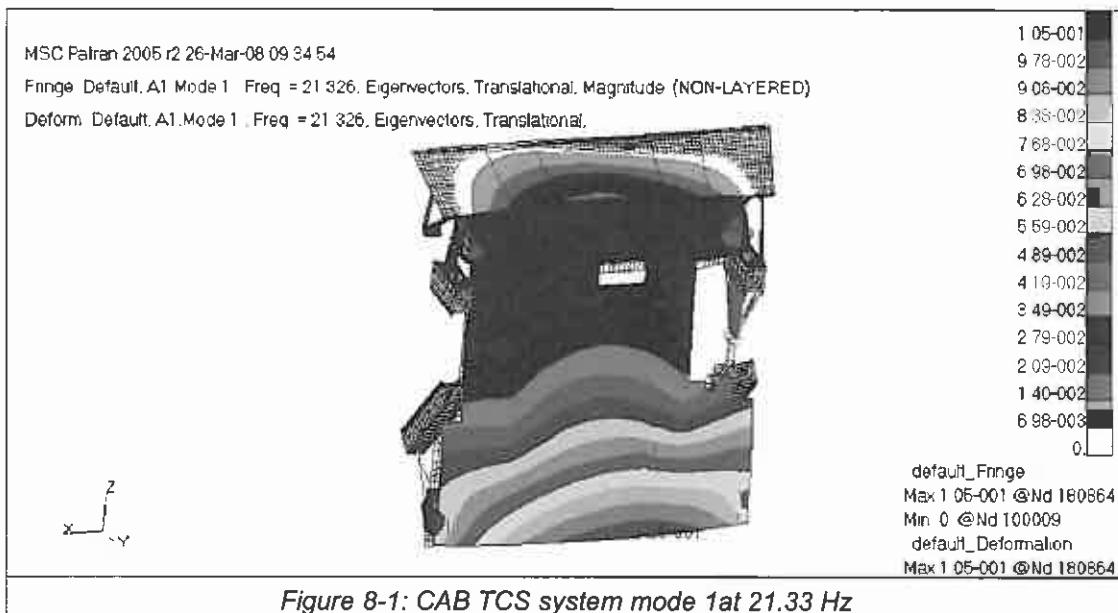
Pagina  
Page

28

di  
of

41

In the following figures the shapes of the Loop Heat Pipes transport lines modes and the modes with effective mass greater than 5% are presented:





CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:

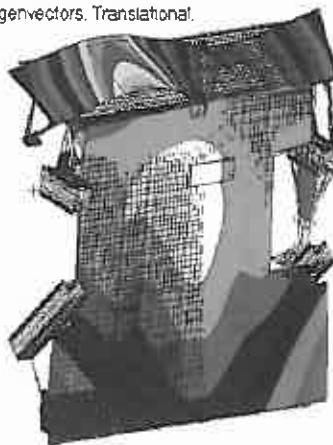
AMSTCS-TN-CGS-008

Doc N°:  
Ediz.:  
Issue:1 Data:  
Date: 27/03/08Pagina  
Page29 di  
of 41

MSC Patran 2005 r2 26-Mar-08 09:36:48

Fringe Default, A1 Mode 3 Freq = 29.84 Eigenvectors, Translational, Magnitude, (NON-LAYERED)

Deform Default, A1 Mode 3 Freq = 29.84 Eigenvectors, Translational.



2.11-001
1.97-001
1.83-001
1.69-001
1.55-001
1.41-001
1.26-001
1.12-001
9.84-002
8.43-002
7.03-002
5.62-002
4.22-002
2.81-002
1.41-002
0

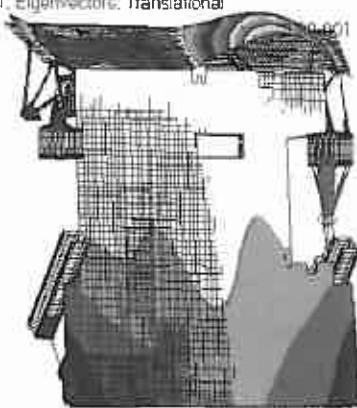
default\_Fringe  
Max 2.11-001 @Nd 171736  
Min 0 @Nd 100009  
default\_Deformation  
Max 2.11-001 @Nd 171736

Figure 8-3: CAB TCS system mode 3 at 29.84 Hz

MSC Patran 2005 r2 26-Mar-08 09:38:22

Fringe Default, A1 Mode 4 Freq = 31.991 Eigenvectors, Translational, Magnitude, (NON-LAYERED)

Deform Default, A1 Mode 4 Freq = 31.991 Eigenvectors, Translational.



3.29-001
3.07-001
2.85-001
2.63-001
2.41-001
2.19-001
1.98-001
1.76-001
1.54-001
1.32-001
1.10-001
8.78-002
6.58-002
4.39-002
2.19-002
0

default\_Fringe  
Max 3.29-001 @Nd 171736  
Min 0 @Nd 100009  
default\_Deformation  
Max 3.29-001 @Nd 171736

Figure 8-4: CAB TCS system mode 4 at 31.99 Hz



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

## CAB TCS STRUCTURAL ANALYSIS REPORT

Nº Doc:  
Doc N°:

AMSTCS-TN-CGS-008

Ediz.:  
Issue:

1

Data:  
Date: 27/03/08Pagina  
Page

30

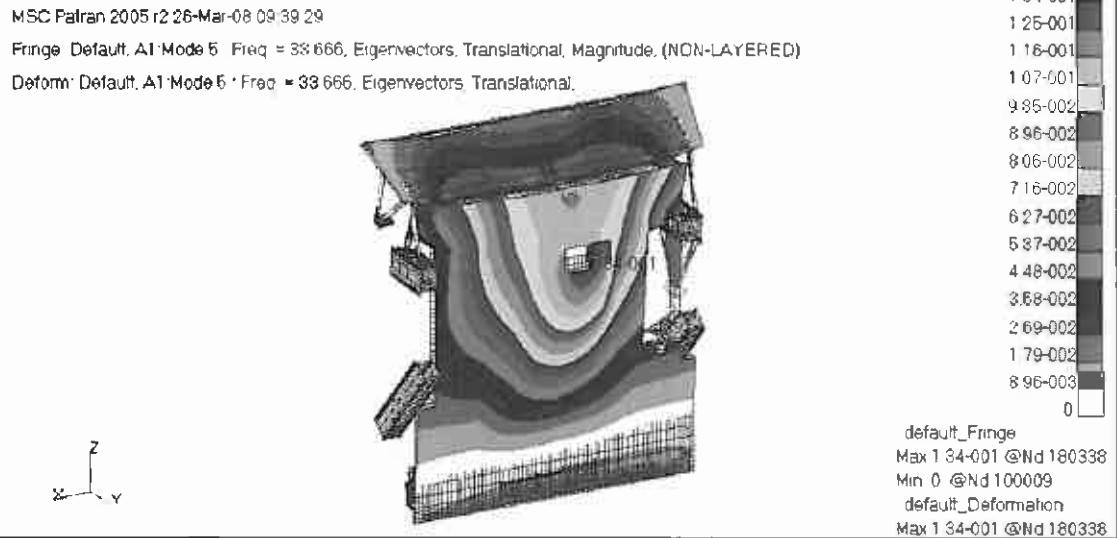
di  
of 41

Figure 8-5: CAB TCS system mode 5 at 33.67 Hz

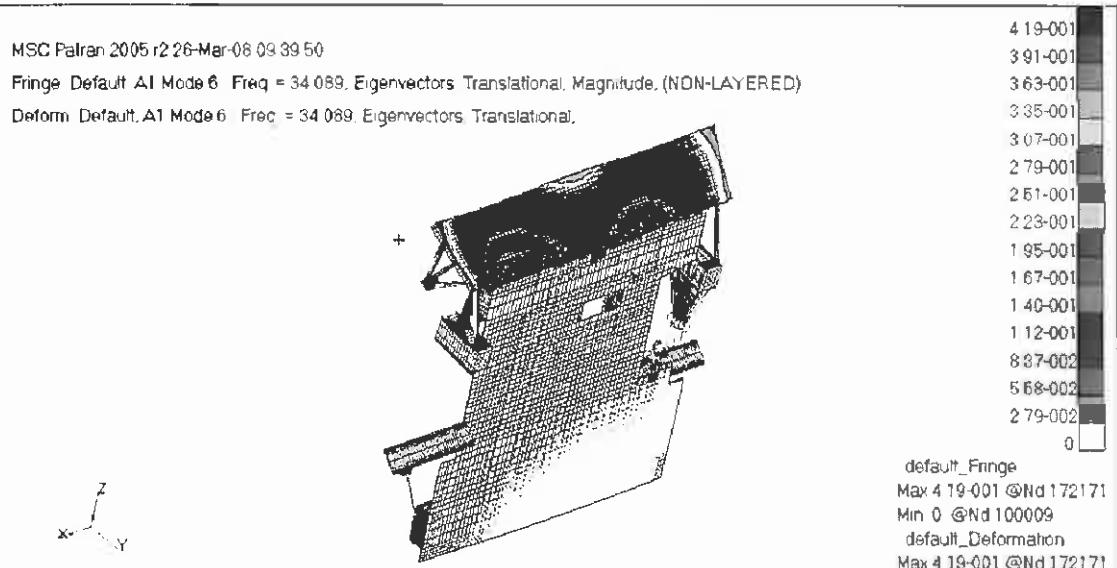


Figure 8-6: CAB TCS system mode 6 at 34.09 Hz



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

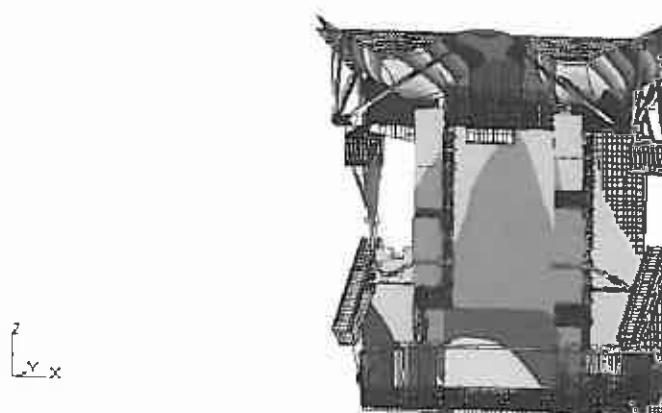
CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°:

AMSTCS-TN-CGS-008

Ediz.:  
Issue:1 Data:  
Date: 27/03/08Pagina  
Page31 di  
of 41

MSC Patran 2005 r2 26-Mar-08 09 40 16  
Fringe Default, A1:Mode 7 Freq = 38.295, Eigenvectors Translational, Magnitude, (NON-LAYERED)  
Deform: Default, A1 Mode 7 Freq = 38.295, Eigenvectors Translational,

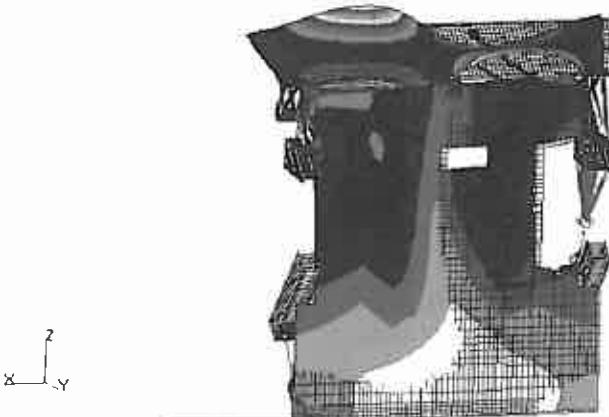


9.25-002  
8.63-002  
8.02-002  
7.40-002  
6.78-002  
6.17-002  
5.55-002  
4.93-002  
4.32-002  
3.70-002  
3.08-002  
2.47-002  
1.85-002  
1.23-002  
6.17-003  
0

default\_Fringe  
Max 9.25-002 @Nd 172174  
Min 0 @Nd 100009  
default\_Deformation  
Max 9.25-002 @Nd 172174

Figure 8-7: CAB TCS system mode 7 at 38.30 Hz

MSC Patran 2005 r2 26-Mar-08 09 40 50  
Fringe Default A1:Mode 8 Freq = 53.327, Eigenvectors Translational, Magnitude, (NON-LAYERED)  
Deform: Default, A1 Mode 8 Freq = 53.327, Eigenvectors Translational,



2.49-001  
2.32-001  
2.16-001  
1.99-001  
1.83-001  
1.66-001  
1.49-001  
1.33-001  
1.16-001  
9.96-002  
8.80-002  
6.64-002  
4.98-002  
3.82-002  
1.66-002  
0

default\_Fringe  
Max 2.49-001 @Nd 171736  
Min 0 @Nd 100009  
default\_Deformation  
Max 2.49-001 @Nd 171736

Figure 8-8: CAB TCS system mode 8 at 53.33 Hz



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

## CAB TCS STRUCTURAL ANALYSIS REPORT

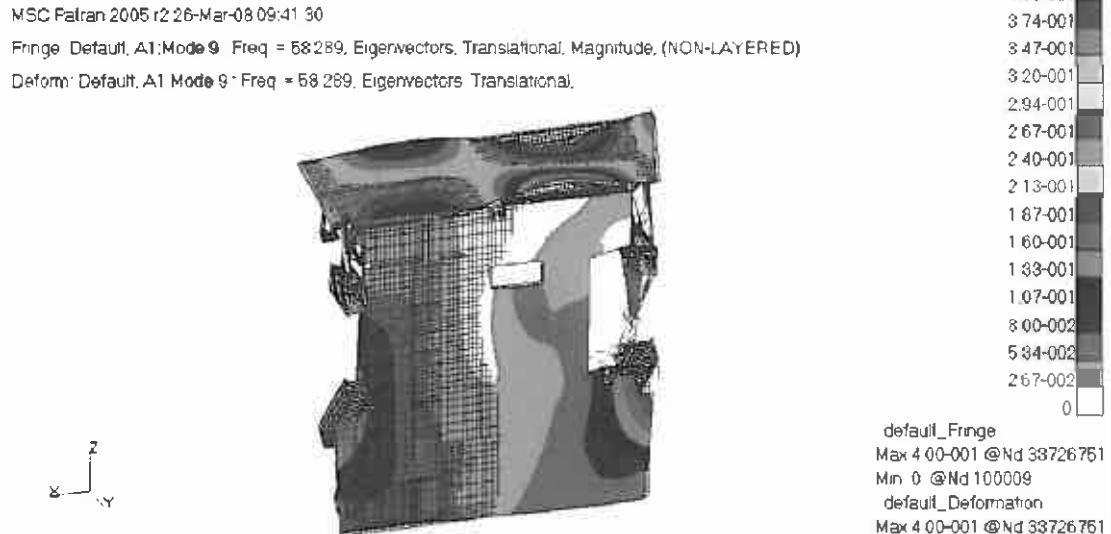
N° Doc: AMSTCS-TN-CGS-008  
Doc N°:Ediz.: 1 Data: 27/03/08  
Issue:Pagina 32 di 41  
Page

Figure 8-9: CAB TCS system mode 9 at 58.29 Hz

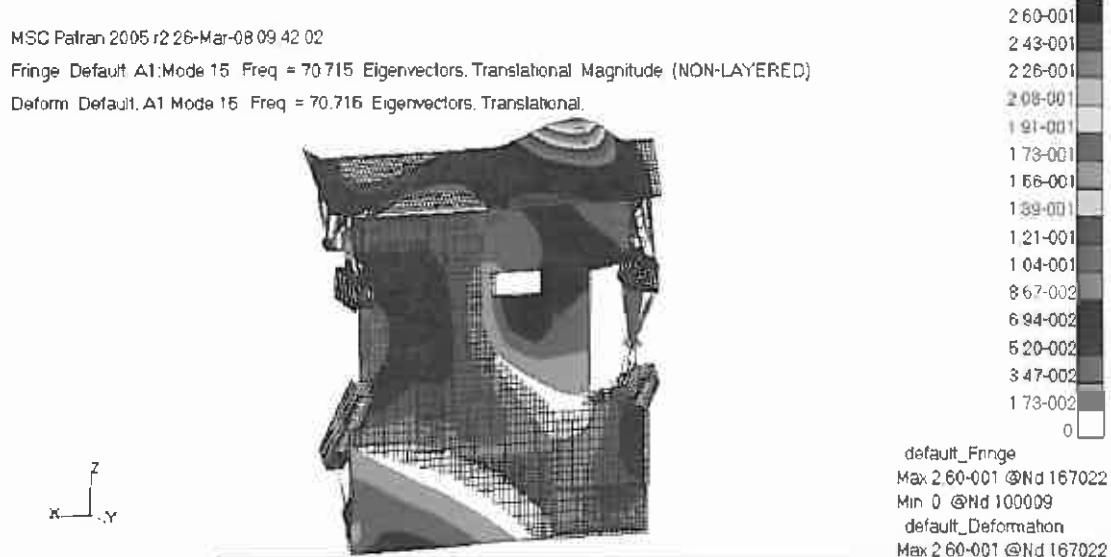


Figure 8-10: CAB TCS system mode 15 at 70.72 Hz



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°: AMSTCS-TN-CGS-008  
Ediz.: 1 Data: 27/03/08  
Issue:  
Pagina 33 di 41  
Page

## 9. STATIC ANALYSIS

In the following sections, static analysis results are described for nominal configuration.

Two different types of results are provided:

- Displacement analysis
- Stress analysis

## 9.1 DISPLACEMENT ANALYSIS

The worst condition is for NODE 179358 for Load Case 1032.

The resulting displacement is 1.26E-2 m.

Following figure shows displacements for this subcase.

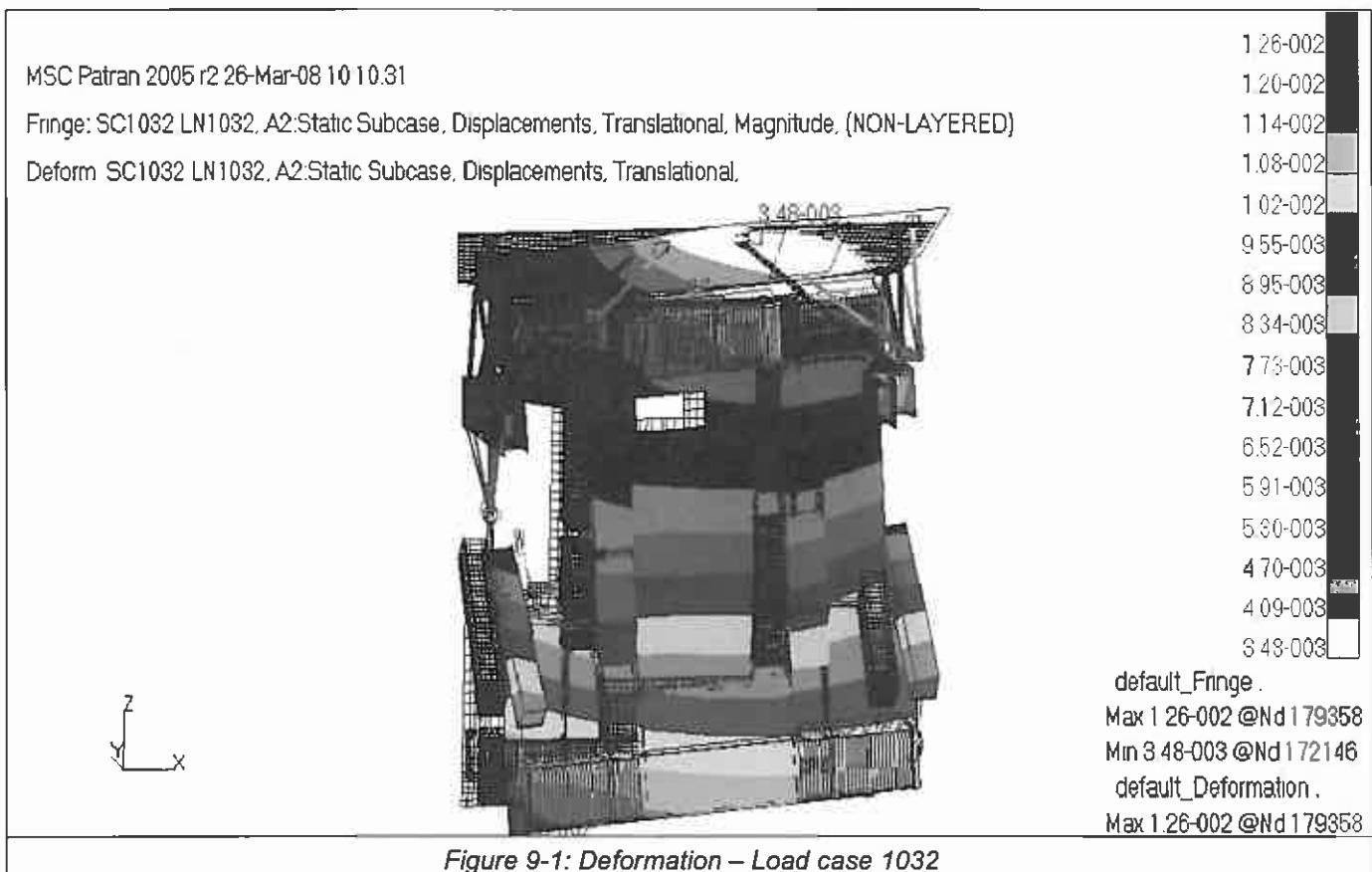


Figure 9-1: Deformation – Load case 1032

In addition the maximum displacement of the CAB LHP transport lines has been evaluated calculating the relative displacement between the pipes and the USS Trunnion bridge.

The worst condition is for NODE 33726753 for Load Case 1017.

The resulting displacement is 4.05E-3 m.

Following figure shows displacements for this subcase.



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

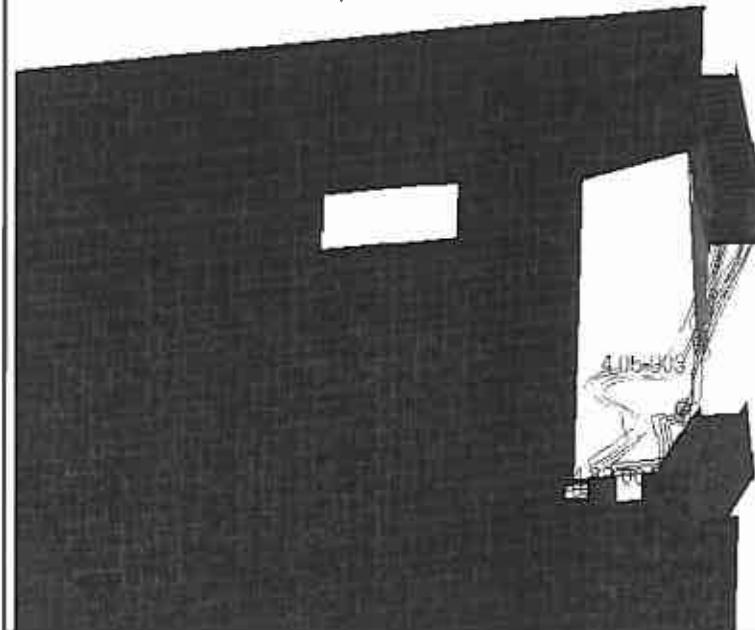
CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc: AMSTCS-TN-CGS-008  
Doc N°:Ediz.: 1 Data: 27/03/08  
Issue:Pagina 34 di 41  
Page

MSC Patran 2005 r2 26-Mar-08 10:37:19

Fringe: SC1017 LN1017, x1, Displacements, Translational, Magnitude, (NON-LAYERED)

Deform: SC1017 LN1017, x1, Displacements, Translational,

4.05-003  
3.81-003  
3.57-003  
3.33-003  
3.10-003  
2.86-003  
2.62-003  
2.38-003  
2.15-003  
1.91-003  
1.67-003  
1.43-003  
1.19-003  
9.57-004  
7.19-004  
4.82-004

default\_Fringe :  
Max 4.05-003 @Nd 33726651  
Min 4.82-004 @Nd 33726832  
default\_Defomation:  
Max 4.05-003 @Nd 33726651

Figure 9-2: Relative displacement LHP transport lines – USS trunnion bridge – Load case 1017

This relative displacement is acceptable with respect to the USS trunnion bridge – LHP transport lines design distance of 15 mm.



CARLO GAVAZZI SPACE SpA

# AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc:  
Doc N°: **AMSTCS-TN-CGS-008**  
Ediz.:  
Issue: **1** Data:  
Date: **27/03/08**  
Pagina  
Page **35** di  
of **41**

## 9.2 STRESS ANALYSIS

The stress contour and MoS calculation for the CAB LHP transport lines is shown in the next pages. The stress contour and MoS for the other WAKE radiator components are reported in the RD8.

The summary of stress analysis results are shown in paragraph 9.2.2 .



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

N° Doc: AMSTCS-TN-CGS-008  
Doc N°:  
Ediz.: 1 Data: 27/03/08  
Issue:  
Pagina 36 di 41  
Page

## 9.2.1 LOOP HEAT PIPES TRANSPORT LINES

The worst condition is for the ELEMENT 11622508 for Load Case 1017.

The resulting maximum combined stress is:  $f_{MC} = 40.1 \text{ MPa}$ .

Following figure shows stress distribution for this subcase.

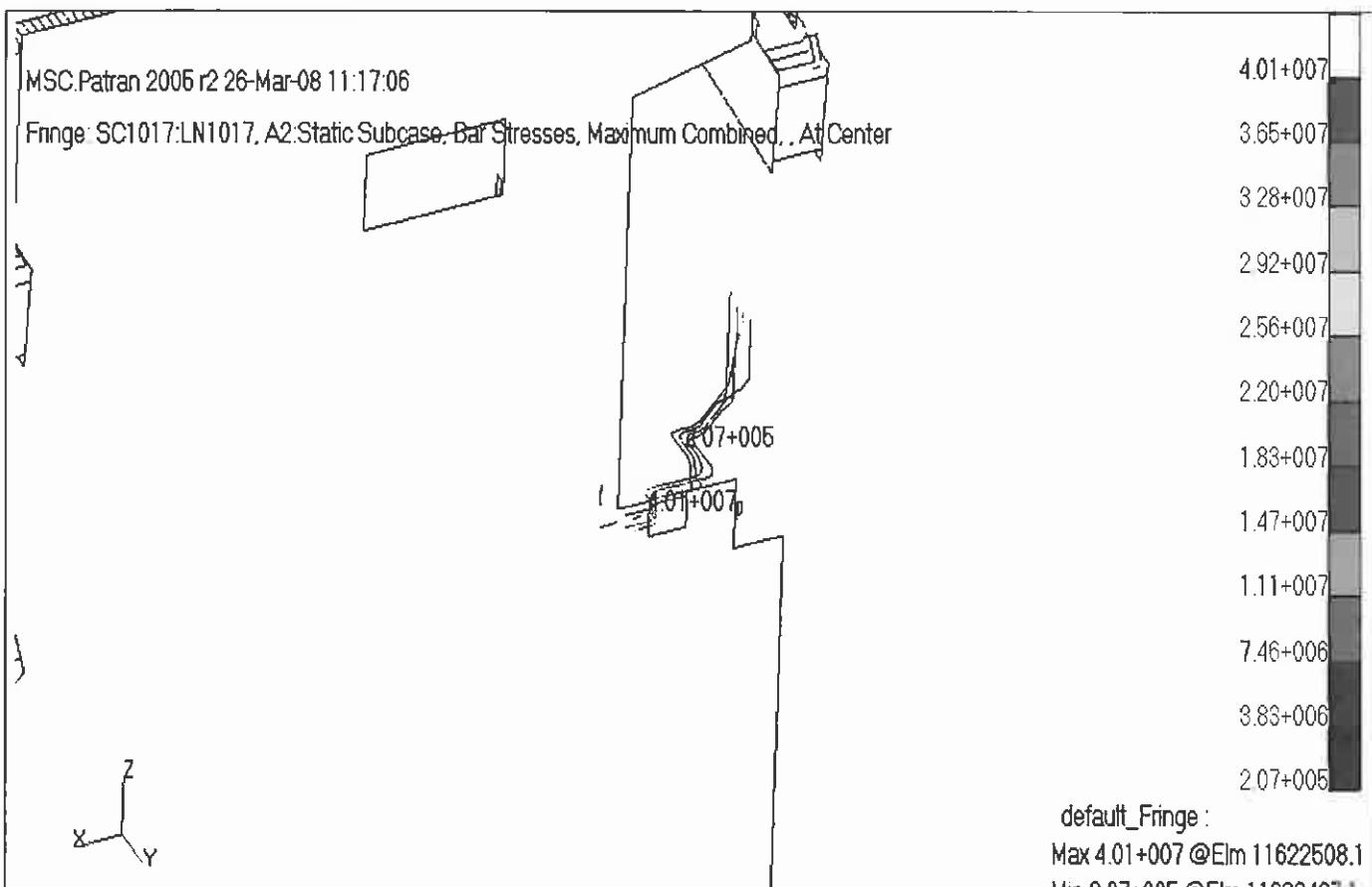


Figure 9-3: LHP bar, Load Case 1017

The upper vapour line has the maximum stress in the tube-wake radiator connection.

The pressure load acting on the Loop Heat Pipe transport lines has to be considered additionally.

Maximum Design Pressure (MDP) is 23 bar (2.3 MPa).

To calculate the pressure induced stresses, LHP Vapour line section with a 2 mm external radius (R) and a 0.5 mm thickness (th).



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

Nº Doc: AMSTCS-TN-CGS-008  
Doc N°:Ediz.: 1 Data: 27/03/08  
Issue:Pagina 37 di 41  
Page

Two kind of pressure effects have been considered.

First one is an induced tension stress on LHP cross section, aligned with LHP axis (see next picture). Pressure of fluid (black arrows) generates a stress on the HP walls (red arrows).

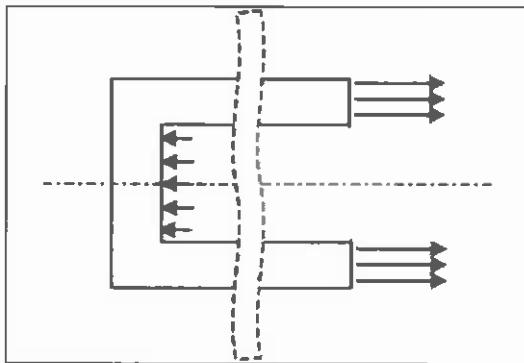


Figure 9-4: Pressure induced stresses 1

$$S1 = MDP * (R-th)^2 / ((R^2 - (R-th)^2) = 3 \text{ MPa}$$
 is the stress on HP walls

Second effect is shown in next image. Radial pressure induces a stress on the gray parts, normal to the LHP axis.

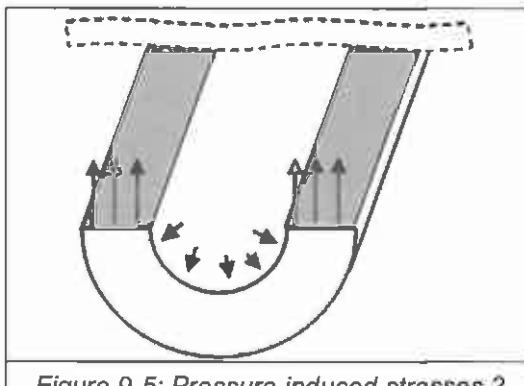


Figure 9-5: Pressure induced stresses 2

$$S2 = MDP * (R-th) / th = 7 \text{ MPa}$$
 is the stress on HP walls

 <b>CARLO GAVAZZI</b> <b>CARLO GAVAZZI SPACE SpA</b>	<h1>AMS02 - TCS</h1>	N° Doc: <b>AMSTCS-TN-CGS-008</b> Doc N°: Ediz.: <b>1</b> Data: <b>27/03/08</b> Issue: Pagina <b>38</b> di <b>41</b> Page
	CAB TCS STRUCTURAL ANALYSIS REPORT	

Considering a safety factor of 2.5 on pressure loads (as per RD 5) the MoS calculation is:

$$SF_u = 2.0$$

$$SF_y = 1.25$$

SF<sub>p</sub> = 2.5 Safety factor on MPD, applied both for yield and ultimate MoS

Sax = 40.1 MPa stress from FE analysis

$$S_1 = 3 \text{ MPa}$$

$$S_2 = 7 \text{ MPa}$$

F<sub>tu</sub> = 557 MPa ultimate tensile stress

F<sub>ty</sub> = 303 MPa yield tensile stress

$$R_{ax\ u} = S_{ax} * SF_u / F_{tu} = 0.144$$

$$R_{1\ pu} = S_1 * SF_p / F_{tu} = 0.0134$$

$$R_{2\ pu} = S_2 * SF_p / F_{tu} = 0.0314$$

$$\text{MoS } u = 1 / ((R_{ax\ u} + R_{1\ pu})^2 + R_{2\ pu}^2)^{0.5} - 1 = 5.23$$

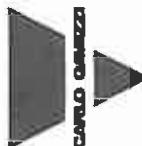
$$R_{ax\ y} = S_{ax} * SF_y / F_{ty} = 0.165$$

$$R_{1\ py} = S_1 * SF_p / F_{ty} = 0.0247$$

$$R_{2\ py} = S_2 * SF_p / F_{ty} = 0.058$$

$$\text{MoS } y = 1 / ((R_{ax\ y} + R_{1\ py})^2 + R_{2\ py}^2)^{0.5} - 1 = 4.03$$

To calculate the MoS it has been taken into account that S<sub>ax</sub> and S<sub>1</sub> are parallel and normal to S<sub>2</sub>.

	<b>AMS02 - TCS</b>	N° Doc: Doc N°: <b>AMSTCS-TN-CGS-008</b>
		Ediz.: Issue: <b>1</b> Data: Date: <b>27/03/08</b>
CAB TCS STRUCTURAL ANALYSIS REPORT		Pagina Page <b>39</b> di <b>41</b> of

## 9.2.2 MARGINS OF SAFETY

In the following table MoS of the structure are showed:

<b>MARGINS OF SAFETY FOR STRENGTH FAILURE (STRESS)</b>								
ITEM	DRAWING NUMBERS	LC	EID	MATERIAL	Fy [MPa]	Flu [MPa]	FEM LIMIT STRESS [MPa]	PRESS. S1 STRES S <sub>1</sub> [MPa] S <sub>2</sub> [MPa]
Loop Heat Pipes transport lines	1017	11622508	AISI 316L	303	557	40.1	3	7

Table 9-1: MoS summary

PRESS.  
S2  
STRES  
S<sub>2</sub> [MPa]

S.F.u  
S.F.p

MoSy

MoSu

NOTES

CHAPTER  
REFERENCE  
PAGE

Maximum  
Combined Stress  
and internal  
pressure induced  
stress have been  
considered

36



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

### CAB TCS STRUCTURAL ANALYSIS REPORT

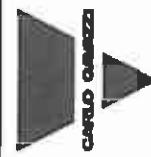
Nº Doc:  
Doc N°: AMSTCS-TN-CGS-008  
Ediz.:  
Issue: 1 Data: 27/03/08  
Pagina  
Page 40 di  
of 41

## 10.CONCLUSIONS AND COMMENTS

The performed analyses of the CAB TCS LHP transport line structure show the following results:

- The 1<sup>st</sup> natural frequency of the WAKE radiator is 21.33. Hz (coincident with the RD8 results) and the 1<sup>st</sup> frequency of the Loop Heat Pipes transport lines is 26.28 Hz, see chapter 8.1 . The LHP transport lines addition to the WAKE radiator FE model doesn't introduce differences on the 1<sup>st</sup> natural frequency of the WAKE radiator system, therefore the performed modal survey test on the WAKE STA (RD9) without the LHP transport lines is considered even dynamically representative of the pipe routing insertion.
- The LHP transport lines displacement wrt the USS trunnion bridge is 4.05 mm. This displacement is compatible with the available envelope, see chapter 9.1
- The MoS are positive for all applied loads; see chapter 9.2.2 for the stress verification

Results of all the performed analyses show that the CAB TCS LHP transport line structure can withstand the dimensioning loads without any rupture and/or any detrimental deformation with the application of the specified safety factors: all structural requirements shown in AD1 are fulfilled.



CARLO GAVAZZI SPACE SpA

## AMS02 - TCS

CAB TCS STRUCTURAL ANALYSIS REPORT

Nº Doc: Doc N°:	AMSTCS-TN-CGS-008
Ediz.: Issue:	1
Pagina Page	41 di 41

### ANNEX 1

#### TABLES FOR SAFETY REVIEW

MARGIN OF SAFETY FOR CAB TCS						
Item	Drawing no	Material and Temper	Material Allowable stress [ksi]	Max. Applied Stress [ksi]	Ratio of Applied limit stress to allowable stress	Margin of Safety (ult) FS=2
Loop Heat Pipes transport lines	AISI 316L - Annealed	80.8	7.35	0.091	0.16	Stress due to delta pressure included with a SF 2.5